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**CONCEPTUAL DESIGN FOR A FOOD PRODUCTION, WATER
AND WASTE PROCESSING, AND GAS
REGENERATION MODULE**

by

**Regenerative Concepts Group
O. W. Nicks,
Principal Investigator**

**Semi-Annual Progress Report
Grant No. NAG 9-161**

November 15, 1986

**Submitted by
Space Research Center
Texas A&M University
College Station, Texas 77843-3118**

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Submitted to

**NASA Johnson Space Center
Houston, Texas 77058**

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CONCEPTUAL DESIGN FOR A FOOD PRODUCTION, WATER AND WASTE PROCESSING, AND GAS REGENERATION MODULE

INTRODUCTION

This is a six-month progress report on the subject activities of an interdisciplinary team at Texas A&M University. Leadership for the team is provided by the Space Research Center. Participants in the study effort are representatives from the departments of Agricultural Engineering, Biology, Chemistry, Industrial Engineering and Mechanical Engineering.

The team was initially assembled during proposal preparation in the fall of 1985. Frequent meetings were held during this period and during the Spring of 1986 prior to official project start on May 15, 1986.

Food, air and water provisions for manned missions in space have employed methods similar to those used on oceangoing vessels and airliners. Chemical and mechanical systems have provided processing of atmosphere and water, but food has been prepackaged and stowed on-board for use during the mission. Solid waste products have been collected and returned to earth for disposal.

The interdisciplinary team assembled at Texas A&M University includes researchers who have experience in the basic technologies relevant to Closed Ecological Life Support Systems, however, efforts were required to obtain up-to-date knowledge of existing space systems and to review research from the past several years addressing the closed ecological question. Ultimately, space qualified systems may employ combinations of biological, physical and chemical components in parallel, or perhaps redundantly. The "fresh eyes" approach to adapting biological technologies with chemical-physical systems is believed to have merit for providing food supply for long duration missions and for recycling waste products in the most useful manner. Emphasis on efficient recycling, led to a goal of regenerative application of all food, air, water and waste products, whether for reuse in the same form, or for making materials, providing energy, or other needed products for use in space. With this broad goal in mind, the team is called Regenerative Concepts (RECON) Group.

REGENERATIVE CONCEPTS GROUP TEAM PARTICIPANTS

Space Research Center

Oran W. Nicks, Project Leader

Frank Little, Project Coordinator

Gloria Johnson, Administrative Coordinator

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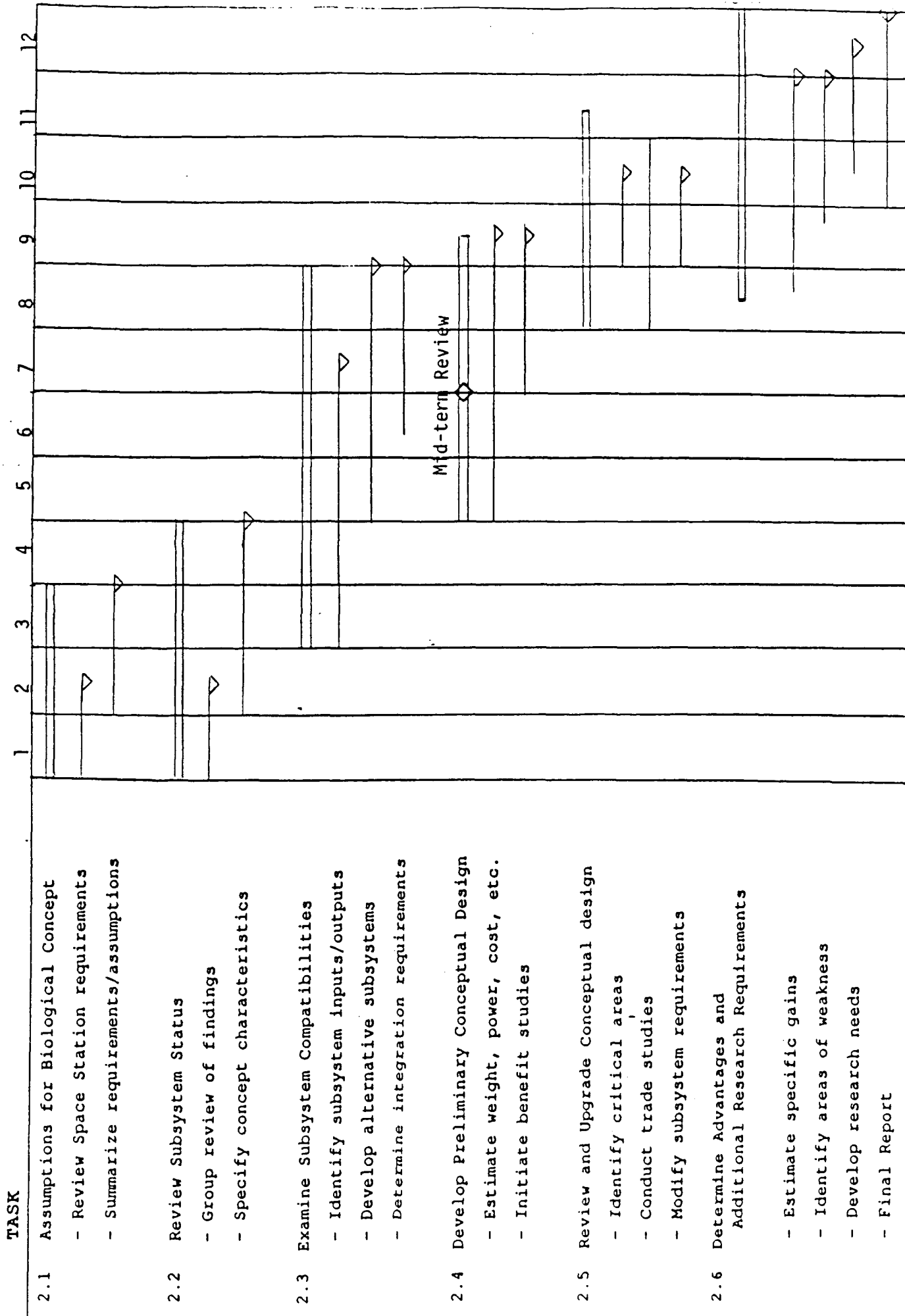
SUMMARY

During the first six month period, the RECON team was assembled and working relationships were established. By agreement, the group elected to meet weekly and to remain closely coupled during the information gathering, concept planning phase. A significant amount of reference material has been collected, visits were made to communicate with other researchers, and distinguished visitors were invited to provide presentations on the status of closed life support activities. A decision was made to develop the data base and modeling such that artificial intelligence (AI) methods could be used to manipulate data and examine concept alternatives.

In the proposal, six discrete tasks and a project schedule were outlined for the first year, Figure 1. The first two tasks have been essentially completed and have resulted in a sample set of assumptions for general use in defining candidate systems and for the specification of closed system characteristics. To model a closed environment, decisions were necessary to establish the amounts of food, air, water and waste products. Although it was recognized that data would eventually be normalized on the basis of a single human, the amounts of data in existence for four person crews led to a decision that this number would be used as a baseline (see Appendix I). Information on existing concepts was collected from NASA sources, from industry and from library references. The group decided to adopt an artificial intelligence approach to concept modeling. Concept modeling was begun, and hardware and software were obtained. Technical tasks were identified and key questions for initiating experiments were outlined.

FIGURE 1.

SCHEDULE OF STUDY ACTIVITIES



TEAM APPROACH

By agreement, the team members met weekly for exchanges of technical information, to work together in developing concept models, and to establish a framework for meaningful experiments. The group of scientists and engineers has an overall goal of answering scientific questions dealing with the integration of biological systems, plus the development of engineering answers essential to the design of practical systems.

Examples of concept modeling are provided in the Appendix. A "bottom-up" approach was used starting with the most basic considerations of gases, liquids and solids. Regular assignments among the team members provided tutorial sessions sharing background information and fundamentals from the point of view of the biologist, chemist, plant scientist, fluids engineer, etc. Discussions on artificial intelligence techniques and requirements for successful modeling were also included.

The RECON group tutorials included the following subjects:

1. Electrochemistry for Hydrogen production by electrolysis
2. Electrochemical coal decomposition
3. Heat transfer studies
4. Function modeling for AI application
5. Food production including:
 - Agriculture cropping system management
 - Higher plant growth requirements
 - Algal capabilities
 - Non-photosynthetic (bacterial) food production
 - Food processing
6. Biological recycle of organic wastes
7. Biological atmosphere closure experiments

Information was provided by astronaut Owen Garriott, who spent months in orbit on Skylab and Spacelab missions. Ric Mayer, from the Knowledge Based Systems Laboratory at Texas A&M, helped to acquaint the group with current AI technologies. Bob Murray, Program Manager from General Electric, who was responsible for the development and use of an experimental waste management system in the 1970's, provided insight concerning mechanical and chemical processing technologies.

ARTIFICIAL INTELLIGENCE EQUIPMENT AND SOFTWARE

After an unexpectedly long negotiation process, a Xerox 1108 workstation has recently been provided by Microelectronics and Computer Technology Corporation through an agreement for the dedicated use of the RECON group. An investment was made by the Space Research Center for AI software (KEE) to be used in this project. Now that the equipment and software are in place, it is planned that development of a CELSS data base and a concept modeling framework will proceed and form the foundation for future work. Arrangements have been made for a demonstration of an expert system developed for JSC to diagnose and correct faults in a prototype space station life support system. The demonstration will illustrate the use of AI technology to RECON team members, and provide a basis for subsequent concept modeling.

All of the data collection efforts will be accompanied by continuing systems modeling, integrating study results from Texas A&M as well as those of others. The successful development of an AI modeling capability should greatly enhance the use of the growing data base for concept design trade-off studies.

TECHNOLOGY TASKS IDENTIFIED

Biological Applications for Atmosphere Regeneration and Food Production:

Incorporating biological systems into the space environment raises significant questions concerning the effects of low pressures on plant growth, and the use of nutrients and gas exchange processes. Since nitrogen in the atmosphere appears to offer little benefit to plants, it is thought that plants may do well in atmospheric environments without the partial pressure normally provided by this gas. For plants grown on the moon, for example, some form of pressure containment would be necessary. The structural requirements for such containment would be significantly reduced by lower internal pressures. Therefore, it seems important to obtain detailed knowledge of the effects of pressure and various ratios of CO₂, O₂ and N₂ on the kinetics of plant processes. The literature which was surveyed produced relevant studies, but these were inconclusive because of their short duration and non steady-state nature. In addition to the question of how to grow plants is the question of what to grow. Plant selection can be based on factors important for nutrition, oxygen regeneration or some optimized combination. Growth rate of the plant and percent of edible biomass are other important factors in plant selection. Crop maintenance, sustainability of yield, and ease of harvest and post harvest processing are important secondary characteristics. Experimental efforts with a view toward obtaining scientific and engineering information from the same experiments are needed.

During the 1960's, preliminary designs for bioregenerative life support systems were developed by NASA, Air Force, and industrial contractors. Progress was made toward the development of workable systems; however, when plans were postponed for the Manned Orbital Lab and for Space Station in favor of emphasis on Space Shuttle, most of the research was discontinued. The short missions and limited crew sizes did not warrant the complexity of bio-regenerative systems.

With interest once again turning to lengthy missions involving crews of four persons or more, the design of such closed systems has again become pertinent and algal-based systems are attracting new interest. One promising aspect of using algal cultures as components of regenerative life support systems is the efficiency with which

they can be grown. The ease with which they can be handled and manipulated (more like chemical reagents than plants), and the culturing techniques available, result in much higher growth rates (and thus much higher gas exchange rates) than are usually attainable with higher plants. Furthermore, several promising new strains of algae have been brought under domestication since the earlier work was done, and important improvements in culture techniques have been made.

One of the RECON team members has extensive experience with algal culture techniques and with experimental work on algal biochemistry. He has proposed experimental projects to extend our understanding of how these microscopic photosynthetic organisms could be best utilized in life support applications. Although this earlier work provides a baseline for our conceptual designs in the present project, additional engineering data must be collected and trade-off evaluations made before practical systems can be designed.

Waste Management Systems:

Waste management systems are central to the design of CELSS. Without processing allowing reuse, a contractor study showed the logistic requirements for a projected 90-day supply of potable and hygiene water would total over half of the Shuttle payload capacity. Wash and waste water being returned to earth were estimated to significantly exceed the Shuttle landing payload capacity.⁽¹⁾

Electrochemical treatments are of great potential value in the conversion of solid waste and water of low purity, to reusable gases. The concept being studied in detail by the RECON group will involve an electrochemical reactor, or electrolyzer, containing an anodic and cathodic compartment. Waste solids are added to these compartments where they may be mixed with urine, feces, or waste water. A potential is applied to the working electrodes causing the breakdown of solid material to CO₂.

The principle and feasibility of solid waste treatment using this method were demonstrated by Bockris and colleagues ⁽²⁾, who observed a high faradaic efficiency and product efficiency of the electrochemical breakdown of biopolymers to CO₂.

Most of the solid material of human feces is made up of carbohydrates. Because electrochemical methods have been devised for the conversion of even insoluble carbonaceous material to CO_2 , it seems likely that electrochemical techniques will be able to treat most of the waste materials likely to be produced during a manned space mission.

The types of waste that may be electrolyzed to give usable gases are:

- 1) feces
- 2) urine
- 3) plant waste
- 4) impure water
- 5) disposable containers made of biodegradable polymers.

Up to this point, emphasis has been placed on electrolysis as a means of recycling carbon based compounds to give CO_2 which is then supplied to gas conversion systems. However, electrolysis of solid waste will also play a central role in water management. During the electrolysis, large amounts of H_2 will be evolved, at the cathodic compartment, from the waste slurry. H_2 can be supplied to fuel cells to provide electrical energy and to give water which may be reused. H_2 is also a primary nutrient in some chemosynthetic bioregenerative systems (3).

Physiochemical waste management systems have recently been assessed for use in CELSS⁽¹⁾. The following systems were evaluated:

- a) incineration (INCIN)
- b) wet oxidation (WETOX)
- c) supercritical water oxidation (SCWO)
- d) vapor compression distillation (VCD)
- e) thermoelectric integrated membrane evaporation system (TIMES)
- f) vapor-phase catalytic ammonia removal (VPCAR)

An attempt will be made to assess the above systems in comparison with the electrochemical waste treatment concept; however, the reader should bear in mind that in making comparisons, these systems are at different stages of development.

INCIN, WETOX, SCWO are systems designed to process both liquid and solid waste. These systems have disadvantages in that they have high heat rejection properties and high power requirements, which is especially true for initiation of SCWO. INCIN and WETOX both produce effluent that requires post treatment catalytic oxidation. These systems have high weight and volume requirements compared to the other systems (TIMES, VPCAR, VCD) listed above.

Electrochemical treatments of waste do not require elevated temperatures. Advanced electrochemical processing, combined with convenient methods for controlling the electrode reactions will greatly reduce the amount of residue to be disposed of. Methods have been devised that will allow even insoluble carbonaceous material, such as coal, to be efficiently converted to CO_2 . The electrolyzer may be made of light-weight materials using technology associated with light weight fuel cells. Electrochemical treatments will afford a great deal of control over the breakdown process. Thus, the operation of the system may be adapted to the requirements of individual missions.

VCD, TIMES and VPCAR were designed for use in water recovery. They have advantages over WETOX, SCWO, INCIN, in that they have low power requirements and are relatively light. Their disadvantage is that they cannot process water that contains appreciable amounts of impurities. These processes leave a brine-like residue which poses logistical problems thereby limiting the use of these systems for long term space missions.

Nevertheless, it is possible to develop a conceptual design for waste management in which VCD, TIMES, or VPCAR may be used in water recovery and where the residue from these processes, together with low quality water and solid waste is treated electrochemically.

Electrochemical CO₂ Reduction and the Production of Food:

Since the mid-1960's, a significant amount of work has been done to demonstrate the feasibility of non-photosynthetic microorganisms for use in CELSS. Electrochemical methods play a key role in the maintenance of these so-called chemosynthetic systems which are a realistic alternative to higher plants as a means of gas exchange and food production. These systems, which involve the continuous growth of microbial cultures, offer many advantages in terms of weight/volume requirements, ease of automation, efficiency (no illumination is required), economy and fault tolerance. The use of this type of food production has become tenable given the highly developed state of food processing which can render almost any basic food palatable.

Efforts are underway ⁽⁵⁾ to develop yeasts grown on methanol as potential food for CELSS. The highly advanced genetic manipulation systems that are available for these microorganisms has made possible the development of strains which contain an increased content of digestible carbohydrates to better meet optimal human dietary requirements.

Electrochemical CO₂ reduction to simple organic molecules is of primary importance to this method of food production. Attempts to provide energy efficient methods of CO₂ reduction, to produce methanol have generally had little success. However, rapid improvements in the efficiency of this process are likely, given both the importance now attached to photoelectrochemical systems for the production of easily stored liquid fuels and the rate at which new catalysts are becoming available ⁽⁶⁾.

Chemosynthetic systems have been developed based on the bacterium *Hydrogenomonas eutropha* ^(4,7). This system is based upon the electro- chemical splitting of water (to give H₂ and O₂) which, together with urine and CO₂ from the astronaut, are the primary nutrients of this microorganism.

This system involved the production of an electrolysis system designed to operate under conditions of weightlessness. This work showed that the material balance between human needs (O₂) and human outputs (CO₂ and urine) could be

maintained by a 20 liter culture of *H. eutropha* which would also supply 0.72 kg of potential food per day.

Since this work, considerable advances have been made in technology associated with continuous microbial culture; these systems represent a realistic option for food generation on long-term space missions.

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APPENDIX

A large amount of reference material has been amassed during the first six-month period. Detailed minutes of weekly meetings were prepared and collected, along with many reference materials. These are available to all team members. To illustrate the nature and scope of this reference material, a sample set of excerpts from the weekly minutes is included.

APPENDIX A
Baseline Requirements

ECLSS Requirements
(Condensed from Document no. CSD-SS-059)

Operating Conditions--

Crew: 4 members
Station Temperature: 70°F
Station Pressure: 14.7 psia

Daily Supply Requirements:

| | | |
|--------------------|----------------------------|----------------|
| potable water | 32.4 lb _{m,ss} | 3.9 gal |
| hygiene water | 48.0 lb _m | 5.8 gal |
| clothes wash water | 110.0 lb _m | 13.2 gal |
| dish wash water | <u>50.0 lb_m</u> | <u>6.0 gal</u> |
| TOTAL WATER | 240.4 lb _m | 28.9 gal |

Oxygen (P_{O2}=3.0 psia) 10.2 lb_m 391.2 ft³
(70% of maximum requirement)

Daily Removal Requirements:

| | | |
|--------------------------|---------------------------|----------------|
| 1) Water | | |
| respiration/perspiration | 16.1 lb _m | 1.9 gal |
| other metabolic water | 3.1 lb _m | 0.4 gal |
| urine | 17.6 lb _m | 2.1 gal |
| food | <u>4.4 lb_m</u> | <u>0.5 gal</u> |
| TOTAL WASTE WATER | 41.2 lb _m | 4.9 gal |

| | |
|--------------------|----------------------------|
| 2) Solids | |
| food | 5.44 lb _m |
| urine | 0.52 lb _m |
| feces | 0.28 lb _m |
| sweat | <u>0.16 lb_m</u> |
| TOTAL WASTE SOLIDS | 6.40 lb _m |

3) Carbon Dioxide
CO₂ (P_{CO2}=0.05 psia) 12.3 lb_m 20576.1 ft³
(70% of maximum requirement)

ECLSS Requirements
(Condensed from Document no. CSD-SS-059)

Operating Conditions--

Crew: 6 members
Station Temperature: 70°F
Station Pressure: 14.7 psia

Daily Supply Requirements:

| | | |
|--------------------|----------------------------|----------------|
| potable water | 48.6 lb _m | 5.8 gal |
| hygiene water | 72.0 lb _m | 8.6 gal |
| clothes wash water | 165.0 lb _m | 19.8 gal |
| dish wash water | <u>75.0 lb_m</u> | <u>9.0 gal</u> |
| TOTAL WATER | 360.6 lb _m | 43.4 gal |

Oxygen (P_{O2}=3.0 psia) 15.3 lb_m 586.8 ft³
(70% of maximum requirement)

Daily Removal Requirements:

1) Water

| | | |
|--------------------------|---------------------------|----------------|
| respiration/perspiration | 24.2 lb _m | 2.9 gal |
| other metabolic water | 4.7 lb _m | 0.6 gal |
| urine | 26.4 lb _m | 3.2 gal |
| food | <u>6.6 lb_m</u> | <u>0.8 gal</u> |
| TOTAL WASTE WATER | 61.9 lb _m | 7.5 gal |

2) Solids

| | |
|--------------------|----------------------------|
| food | 8.16 lb _m |
| urine | 0.78 lb _m |
| feces | 0.42 lb _m |
| sweat | <u>0.24 lb_m</u> |
| TOTAL WASTE SOLIDS | 9.60 lb _m |

3) Carbon Dioxide
CO₂ (P_{CO2}=0.05 psia) 18.5 lb_m 30947.8 ft³
(70% of maximum requirement)

General Considerations:

- 1) The above requirements make no provision for EVA requirements.
- 2) No provision is made for emergency conditions.
- 3) Total volume of the station is not incorporated in the gas supply/removal requirements.
- 4) Gas supply/removal volumes are computed at the appropriate partial pressure of each gas.

1.1 SPACE STATION ECLSS REQUIREMENTS SUMMARY

The critical functions of the space station ECLSS include (1) atmospheric pressure and composition control, (2) atmospheric revitalization (3) cabin air temperature and humidity control, (4) water reclamation and management, (5) personal hygiene and waste management, and (6) habitability provisions. The ECLSS shall embody regenerative concepts to an optimal degree to minimize the resupply expendables, and shall have the necessary flexibility and expansion capability to accommodate the phased evolutionary growth of the space station.

The specific design requirements for the ECLSS are listed below:

1. The ECLSS shall control the space station pressurized environment to the values indicated in Table 1.
2. The cabin O₂ shall be supplied by electrolysis of water.
3. Nitrogen shall be used as the diluent gas in the cabin atmosphere. The design goal of the nominal total cabin pressure is 14.7 psia
4. A regenerative CO₂ removal system, which concentrates the CO₂ for further processing, shall be provided to maintain the habitat module CO₂ partial pressure under 3.0 mmHg in nominal operation.
5. The CO₂ collected shall be converted to water.
6. Emergency repressurization gases shall be provided to repressurize either habitat module or any normally-pressurized module independent of any other module, one time from 0 to 10 psia.
7. The humidity condensate collected in the CO₂ reduction and other air revitalization processes shall be first used to produce potable quality water with chemical and physical treatments to satisfy potability requirements.
8. Urine and expended hygiene water shall be processed by a concept incorporating a phase change to produce potable quality water that is acceptable for water electrolysis and other ECLSS uses.
9. Effluent wash water may or may not be processed by a phase change concept, but must be adequately processed to ensure sterility and suitability as cleansing water.

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10. Provisions will be made to prevent objectionable and noxious odors emitted in any location from being transmitted to any habitable location in the space station.
11. The atmospheric constituents, including harmful airborne trace contaminants and odors, will be monitored and controlled in each isolable pressurized habitable volume.
12. Atmospheric leakage of each module shall be less than 0.5 lb/day with a maximum of 5 lb/day for the whole space station pressurized volume.
13. Overboard gas venting is permitted but shall be minimized and controllable. Vents shall be non-propulsive, and shall not degrade solar cell or radiator surfaces.
14. Particulate matter filtration shall be provided in the ECLSS for removal of airborne particles above 300 micron size.
15. The microbial concentration in the environment of each of the pressurized compartments containing crew quarters, process laboratories, or experimental facilities shall be controlled.
16. Capability shall exist for dumping the atmosphere of a module(s) overboard in the event of contamination or fire in the module(s). Exposure of the ECLSS within the normally-pressurized modules to a cabin pressure between 0 and 10 psia shall not create hazards or cause damage to the ECLSS. Provisions to repressurize the evacuated module(s) shall be available from source(s) other than the aforementioned emergency gas supply. The number of repressurizations allowed will be determined by the criticality of each module.
17. The hydrogen contained in the ECLS subsystems shall not cause an explosive hazard if suddenly leaked into the cabin atmosphere.
18. Crew related consumable resupply shall be sized for 90 days based on the 24-hour nominal use rate. A 90-day reserve of consumables shall be provided against the possibility that the normal resupply is interrupted.
19. For at least 21 days in LEO, the electrical power supply shall be able to provide enough power (currently estimated to be 10 KW) for operating the ECLSS at the emergency level for crew survival.

TABLE 1 ECLSS PERFORMANCE REQUIREMENTS

| PARAMETER | UNITS | OPERATIONAL | 90-DAY DEGRADED* | 21-DAY EMERGENCY |
|------------------------|-------------------------|----------------------------------|---------------------------------|---------------------------------|
| CO2 Partial Pressure | mmHg | 3.0 Max | 7.6 Max | 12 Max |
| Temperature | deg F | 65 - 75 | 60 - 85 | 60 - 90 |
| Dew Point** | deg F | 40 - 60 | 35 - 70 | 35 - 70 |
| Ventilation | ft/min | 15 - 40 | 10 - 100 | 5 - 200 |
| Potable Water | lb/man day | 6.8 - 8.1 | 6.8 min | 6.8 min |
| Hygiene Water | lb/man day | 12 min | 6 min | 3 min |
| Clothes Wash Water | lb/man day | 28 min | 14 min | 0 |
| O2 Partial Pressure*** | psia | 2.7 - 3.2 | 2.4 - 3.8 | 2.3 - 3.9 |
| Total Pressure | psia | 14.7 | 10 - 14.7 | 10 - 14.7 |
| Trace Contaminants | --- | 24 hr. industrial standard | 8 hr. industrial standard | 8 hr. industrial standard |
| Microbial Count | per ft3 | 100 | --- | --- |
| Maximum Crew Member | per space station | 8 | 8 | 12 |
| Maximum crew Member | per Habi- tat module | 4 | 8 | 8 |

* Degraded levels meet "fail operational" reliability criteria.

** In no case shall relative humidities exceed the range of 25 -75 %.

*** In no case shall the O2 partial pressure be below 2.3 psia, or the O2 concentration exceed 26.9%.

The ECLSS also includes the space station extravehicular activity work system which is comprised of all equipment required to support the anticipated construction and service missions outside the space station. The specific design requirements for the EVA system are listed below:

The maximum EVA duration will be eight hours/man/24-hour day. Eight hours is in addition to 30 minutes each of pre and post-EVA activities.

The space station must provide the capabilities to reservice the reusable EMU life support subsystem including the reprocessing of crew's metabolic CO₂ and waste H₂O and the refreezing of the non-venting heat sink. Reservicing capabilities shall be based on 24-hour EVA's per week as a minimum.

"pre-breathe" by an EVA crewman shall be required prior to an EVA suits will be pressurized with oxygen.

The space station must support multiple EVA's during any given time frame and to eliminate procedural or safety concerns the space station shall provide multiple EVA airlocks.

The space station is required to provide a variable, controlled rate of depressurization and pressurization of the EVA airlocks. Nominal rate is not to exceed 0.1 psi/sec. The emergency rapid rate depressurization and repressurization is not to exceed 1 psi/sec. Depressurization/pressurization control shall be possible from inside and outside the space station and inside the airlocks. Support umbilical connectors shall be available outside the airlock to allow umbilical EVA operations.

The space station shall be designed to conserve and minimize airlock consumable losses as a result of an EVA. The airlock shall function as a hyperbaric chamber capable of 3 atmospheres. The airlock shall also be responsive to emergency, quick EVA requirements and will provide all EMU support during airlock depressurization and repressurization.

Provisions for EVA preparation, EVA equipment storage, recharge, checkout, maintenance and post-EVA activities shall be made in the airlock or in an adjacent pressurized compartment. The maintenance must accommodate stowage of EMU spare parts and tools. Provision to verify the acceptability of an EMU for EVA following its use or resizing must be available in the work area.

8. A window shall be placed close to the airlocks to allow an observer to have visual contact with an EVA astronaut immediately after his/her egress.

9. Voice communications and visual surveillance of the EVA crew shall be provided.

10. Translation means will include hand rails/hand holds and manned maneuvering units (MMU).

11. Hand holds, hand rails, and restraint attach points must be provided along all EVA routes and at each EVA hatch. Attachment provisions for portable handholds and restraint systems must be available at remote work sites.

12. Locomotion, restraint devices and portable EVA workstations will be provided.

13. The space station design shall be able to support simultaneous EVA of two crewmembers during initial operations and up to four crewmembers during subsequent growth phases.

14. A minimum of 2 MMU support stations shall be provided during growth phases. The MMU's shall be protected from the hazards of space vacuum exposure during stowage and servicing.

15. The EMU shall utilize automatic management to the extent possible.

16. EVA audio and visual displays with up and down link capabilities shall be provided.

The general safety, reliability, maintainability and redundancy for the ECLSS are included in the space station requirements set forth by the JSC Space Station Program Office (reference 1). To meet the requirements, the ECLSS shall be fail/safe and fail/operational, i.e.:

1. A failure of any subsystem will not jeopardize the lives of the crew or the integrity of any other subsystem, or cause the evacuation of any module.

2. If the primary unit of any subsystem is inoperational, the backup unit of the subsystem shall be able to perform the critical functions of the subsystem at the nominal level.

3. The capability of performing critical functions will exist at the emergency level, long enough to restore nominal operations, or to rescue the crew to safety.

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1.2 GROUND RULES AND ASSUMPTIONS

To develop the conceptual design for the space station ECLSS which will satisfy the requirements, a number of groundrules and assumptions have been made. They are summarized as follows:

1. Table 2 defines ECLSS nominal design loads, which are based on an average metabolic rate of 11200 BTU/man-day. A metabolic heat generation matrix containing the sensible and latent load split for the crew activities is shown in Table 3.

2. The air-pressurized volumes of the initial space station, will include one habitat, one service, one logistic and two airlock modules. The space station will be inhabited after the basic modules are launched and assembled.

3. The operational space station will include one more habitat, one more service module and an IVA tunnel between the two habitat modules, which will be air-pressurized. Each pair of habitat and service modules will be separately pressurized with an independent ECLSS which is capable of supporting 4 men at the operational level, and 8 men at the degraded level.

4. The volumes of the initial and operational space station modules are estimated to be

| MODULE | GROSS VOLUME(Ft3) | PRESSURIZED VOLUME(Ft3) | HABITABLE VOLUME(Ft3) |
|----------|----------------------|----------------------------|--------------------------|
| Habitat | 7100 | 6390 | 3550 |
| Service | 2000 | 1800 | 1000 |
| Logistic | 2260 | 2030 | 1130 |
| Airlock | 200 | 150 | 140 |
| Tunnel | 1270 | 1140 | 650 |

5. For analysis of transient performance of the space station ECLSS, only the habitable volumes of the habitat and service modules will be considered. A typical crew duty cycle is shown in Figure 1.*

6. The nominal atmospheric pressure and composition requirements specified in Table 1 are for the habitat modules only. The atmosphere in other pressurized modules will be allowed to exceed the nominal level but not the degraded level requirements during nominal operation.

7. Only one habitat module and one service module will be completely repressurized one time after evacuation of the modules, in the event of contamination or fire in the modules.

* Figures are attached to the end of the text.

8. ECLS subsystems using or producing hydrogen shall preferably be located in the service module. Passing hydrogen through docking or berthing interfaces shall be avoided as a design goal.

9. Solar array power will be available in the 56-minute sunlit phase of a 92-minute space station orbital period. During the earth-shadowed phase, regenerable battery or fuel cell supplied power will be available. The ECLSS shall be designed so that major power consuming subsystems will use their maximum power draw on the sun-lit phase of the orbit.

10. To evaluate the power penalty of a ECLS subsystem, estimated values (Reference 1) of 34.6 lb/KW for AC and 30.6 lb/KW for unregulated DC are used for sunlit periods, and 496 lb/KW-hr for AC and 375 lb/KW-hr for unregulated DC are used for earth-shadowed periods. The estimates for the earth-shadowed periods are based on the present battery technology envisioned for space station applications. The tremendously high power penalty for the earth-shadowed periods practically dictates that the major power consuming ECLS subsystems will have to operate cyclically.

11. The ECLS subsystem temperature control shall maintain any selected temperature ± 2 deg. F, between the values indicated in Table 1 within the heating or cooling capacity of the subsystem. When heating or cooling load is high, the extreme range of temperatures shown in Table 1 is allowed.

12. The crew's diet will be comprised of 50% freeze-dried, 20% frozen, 30% thermal stable types of food. The water content of the three types of food are 2%, 55% and 65%, respectively.

13. The requirements for the space station ECLSS do not include O₂ generation, CO₂ removal and water reclamation required to support life science and other experiments which will introduce additional life forms into the space station.

14. The effect of the vehicle heat leakage on the ECLSS will not be accounted for.

15. The average EMU heat leak during a typical EVA for space station construction/service mission is 0 BTU/hr into the EMU.

16. The maximum, average and minimum crew metabolic rates during a typical EVA for space station construction/service mission are 2000, 1000 and 400 BTU/hr, respectively. The average metabolic rate of the EVA crewman during the non-EVA period in an EVA day will be the same as that in a non-EVA day, 467 BTU/hr.

17. The ECLSS equipment shall be designed for a minimum operational life of 10 years with resupply of consumables and replaceable items of equipment.

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TABLE 2 ECLS DESIGN AVERAGE LOADS
At A 70 DEG F CABIN TEMPERATURE

| PARAMETER | UNITS | AVERAGE | PEAK |
|------------------------------------|--------------|---------|------|
| Metabolic O2 | lb/man day | 1.84 | 3.65 |
| Metabolic CO2 | lb/man day | 2.20 | 4.41 |
| Air Leakage | lb/day total | TBD | 5.0 |
| EVA O2 | lb/8 hr EVA | 1.32 | |
| EVA CO2 | lb/8 hr EVA | 1.57 | |
| Drink Water | lb/man day | 2.86 | 3.39 |
| Food Preparation Water | lb/man day | 3.90 | 4.64 |
| Hand Wash Water | lb/man day | 7.0 | |
| Shower Water | lb/man day | 5.0 | |
| Clothes Wash Water | lb/man day | 27.5 | |
| Dish Wash Water | lb/man day | 12.5 | |
| Metabolic Produced H2O | lb/man day | 0.78 | |
| Perspiration and Respiration Water | lb/man day | 4.02 | 5.82 |
| Urine | lb/man day | 4.4 | |
| Food Solids | lb/man day | 1.36 | |
| Food Water | lb/man day | 1.10 | |
| Urine Solids | lb/man day | 0.13 | |
| Fecal Solids | lb/man day | 0.07 | |
| Sweat solids | lb/man day | 0.04 | |
| EVA Waste Water | lb/man day | 2.0 | |

TABLE 2 ECLS DESIGN AVERAGE LOADS
At A 70 DEG F CABIN TEMPERATURE (CONTINUED)

| | | | |
|------------------------------|-------------|------|------|
| Sensible Metabolic Heat | BTU/man day | 7010 | 7900 |
| Hygiene Latent Water | lb/man day | 0.94 | |
| Laundry Latent Water | lb/man day | 0.13 | |
| Expende Hygiene Water Solids | % | 0.13 | |
| Waste Wash Water Solids | % | 0.44 | |
| Airlock Gas Loss | lb/EVA | 2.40 | |

TABLE 3 METABOLIC HEAT GENERATION MATRIX

| Cabin Temperature | | Low Metabolic Load | | | | | | 75° | | |
|---------------------------------------|--|--------------------|-----|--------|--------|-----|--------|--------|-----|--------|
| | | 65° | | | 70° | | | | | |
| | | Btu/hr | Hrs | Total | Btu/hr | Hrs | Total | Btu/hr | Hrs | Total |
| Sensible | | | | | | | | | | |
| Sleep | | 230 | 8 | 1840 | 230 | 8 | 1840 | 230 | 8 | 1840 |
| Lt Wk | | 360 | 8 | 2880 | 315 | 8 | 2520 | 270 | 8 | 2160 |
| Md Wk | | 375 | 8 | 3000 | 325 | 8 | 2600 | 270 | 8 | 2160 |
| Total | | | | 7720 | | | 6960 | | | 6160 |
| Latent | | | | | | | | | | |
| Sleep | | 70 | 8 | 560 | 70 | 8 | 560 | 70 | 8 | 560 |
| Lt Wk | | 90 | 8 | 720 | 135 | 8 | 1080 | 180 | 8 | 1440 |
| Md Wk | | 175 | 8 | 1400 | 225 | 8 | 1800 | 280 | 8 | 2240 |
| Total | | | | 2680 | | | 3440 | | | 4240 |
| Total Metabolic Rate (Btu/man-day) | | | | 10,400 | | | 10,400 | | | 10,400 |

| Cabin Temperature | | Nominal Metabolic Load | | | | | | 75° | | |
|---------------------------------------|--|------------------------|-----|--------|--------|-----|--------|--------|-----|--------|
| | | 65° | | | 70° | | | | | |
| | | Btu/hr | Hrs | Total | Btu/hr | Hrs | Total | Btu/hr | Hrs | Total |
| Sensible | | | | | | | | | | |
| Sleep | | 230 | 8 | 1840 | 230 | 8 | 1840 | 230 | 8 | 1840 |
| Lt Wk | | 360 | 5 | 1800 | 315 | 5 | 1575 | 270 | 5 | 1350 |
| Md Wk | | 375 | 9 | 3375 | 325 | 9 | 2925 | 270 | 9 | 2430 |
| Hv Wk | | 390 | 2 | 780 | 335 | 2 | 670 | 270 | 2 | 540 |
| Total | | | | 7795 | | | 7010 | | | 6160 |
| Latent | | | | | | | | | | |
| Sleep | | 70 | 8 | 560 | 70 | 8 | 560 | 70 | 8 | 560 |
| Lt Wk | | 90 | 5 | 450 | 135 | 5 | 675 | 180 | 5 | 900 |
| Md Wk | | 175 | 9 | 1575 | 225 | 9 | 2025 | 280 | 9 | 2520 |
| Hv Wk | | 410 | 2 | 820 | 465 | 2 | 930 | 530 | 2 | 1060 |
| Total | | | | 3405 | | | 4190 | | | 5040 |
| Total Metabolic Rate (Btu/man-day) | | | | 11,200 | | | 11,200 | | | 11,200 |

| Cabin Temperature | | High Metabolic Load | | | | | | 75° | | |
|---------------------------------------|--|---------------------|-----|--------|--------|-----|--------|--------|-----|--------|
| | | 65° | | | 70° | | | | | |
| | | Btu/hr | Hrs | Total | Btu/hr | Hrs | Total | Btu/hr | Hrs | Total |
| Sensible | | | | | | | | | | |
| Sleep | | 230 | 8 | 1840 | 230 | 8 | 1840 | 230 | 8 | 1840 |
| Lt Wk | | 360 | 4 | 1440 | 315 | 4 | 1260 | 270 | 4 | 1080 |
| Md Wk | | 375 | 4 | 1500 | 325 | 4 | 1300 | 270 | 4 | 1080 |
| Hv Wk | | 390 | 8 | 3120 | 335 | 8 | 2680 | 270 | 8 | 2160 |
| Total | | | | 7900 | | | 7080 | | | 6160 |
| Latent | | | | | | | | | | |
| Sleep | | 70 | 8 | 560 | 70 | 8 | 560 | 70 | 8 | 560 |
| Lt Wk | | 90 | 4 | 360 | 135 | 4 | 540 | 180 | 4 | 720 |
| Md Wk | | 175 | 4 | 700 | 225 | 4 | 900 | 280 | 4 | 1120 |
| Hv Wk | | 410 | 8 | 3280 | 465 | 8 | 3720 | 530 | 8 | 4240 |
| Total | | | | 4900 | | | 5720 | | | 6640 |
| Total Metabolic Rate (Btu/man-day) | | | | 12,800 | | | 12,800 | | | 12,800 |

APPENDIX B

Regenerative Concept References

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APPENDIX C
Sample Meeting Summaries

**Regenerative Concepts Group
Summary
Meeting May 19, 1986**

Attending: Carl Aufderheide, Earl Klein, James Magnuson, Bill Moses, Pat Patterson, Bud Peterson, Ed Rykiel, Peter Sharpe, Ben Scharifker, John Schueller, Bruce Wright, and Gloria Johnson.

1. Peterson - Report on John Hall Contact

Bud Peterson contacted John Hall at Langley and discussed his work in closed life support systems. Hall chose to develop a 4-man module because it was easier to use when planning for a safe haven. When doubling up, he uses linear scaling factors for everything, including volume. Hall will share his information, including a computer program for model development. The group asked Peterson to put together a package on Hall's work and circulate it so that the group can decide if they want to use the computer model.

2. Rykiel - Status of Workstation

The original proposal for leasing the Xerox 1108 AI Workstation from MCC fell through because of a tax problem. The next possible steps are:

(1) Submit proposals describing projects using the hardware, and have MCC give us the machines. TAMU would have to pay maintenance costs. If that happens, it will be within three months.

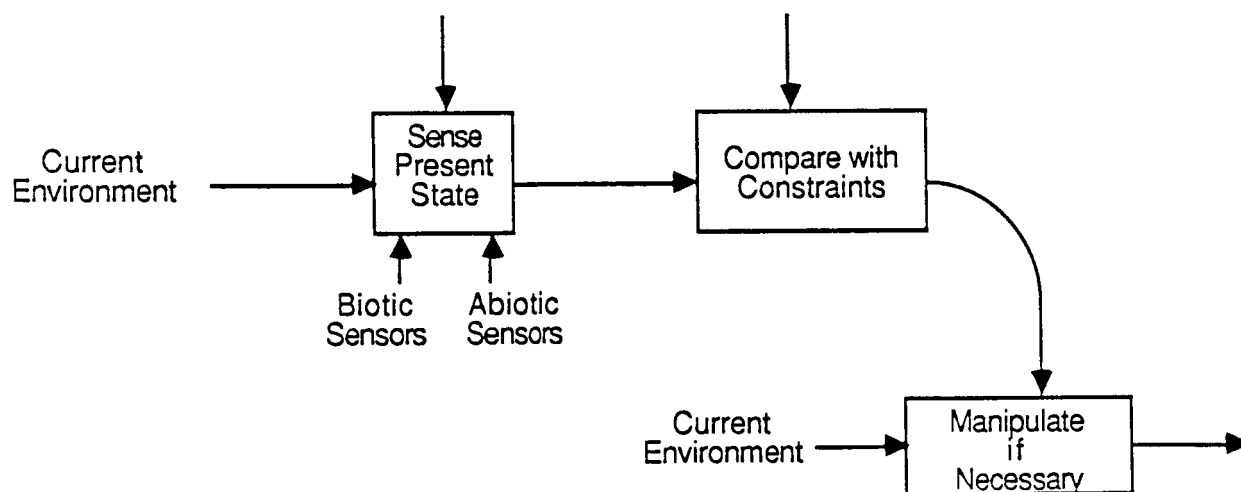
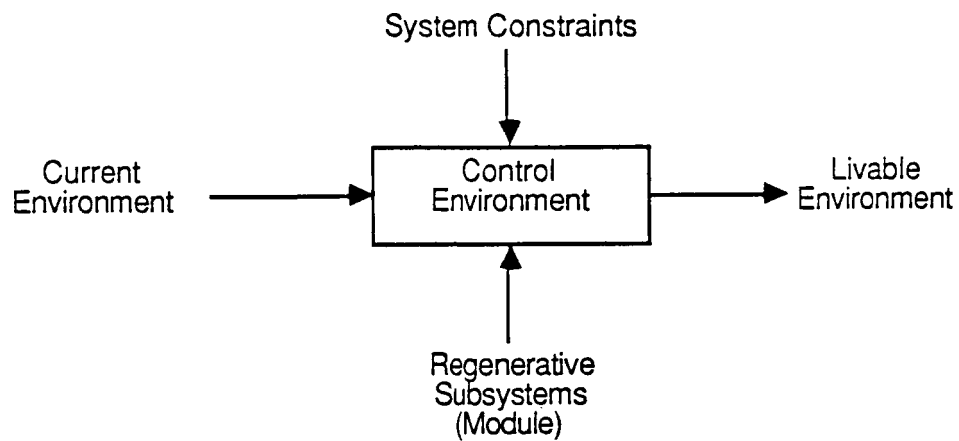
(2) Another possibility will be to use other hardware which can run the KEE software, in the Knowledge Based Systems Laboratory.

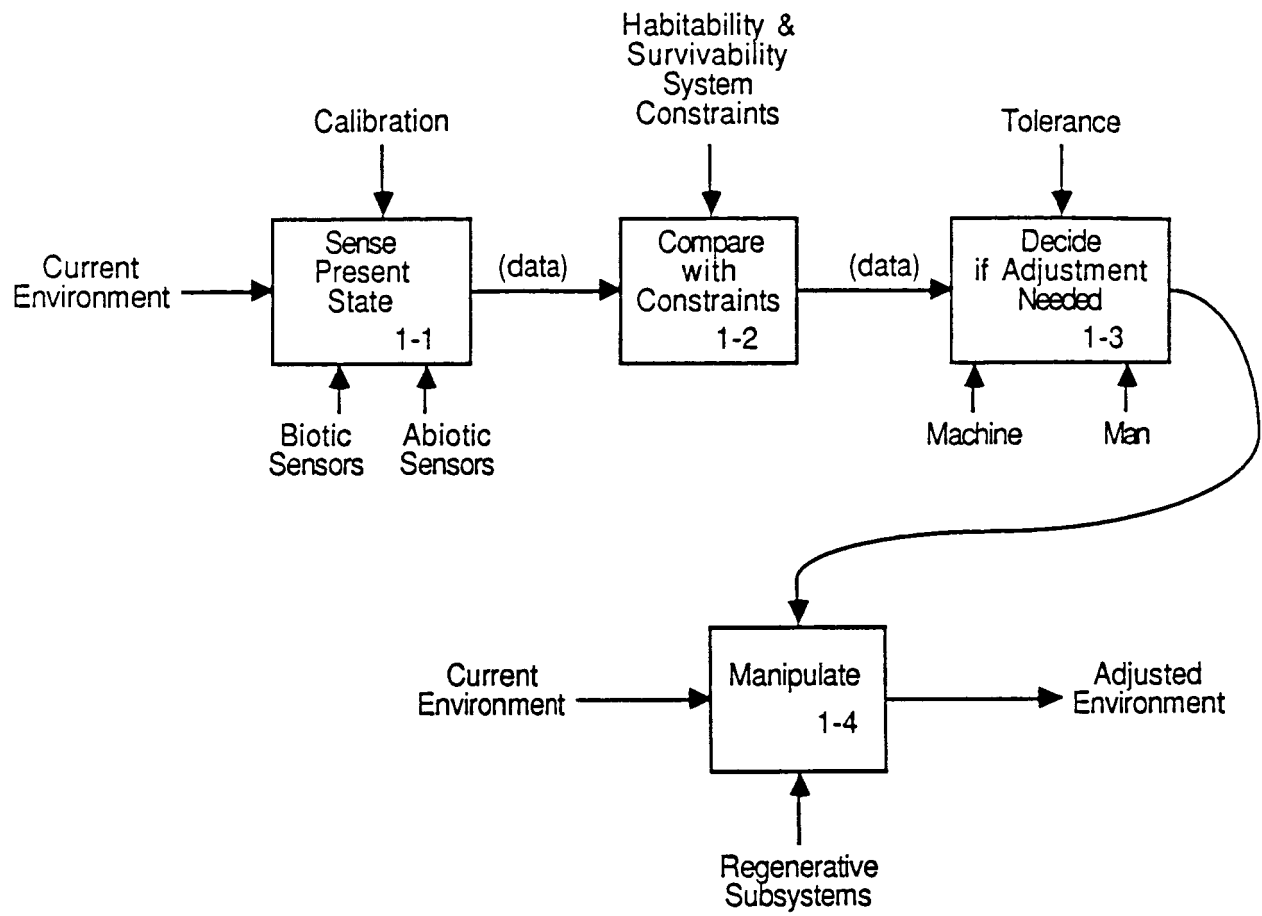
(3) If it is not possible to use the KEE, the project can be done in other ways. Time spent on defining the model will not be wasted, as it will give the group time to develop the concept.

3. Rykiel - Function Modeling

Ed Rykiel gave a presentation on function modeling. The information he used is attached for review by the group before next session. The following diagrams were developed as a first attempt at describing functions necessary for developing the closed life system model. As an assignment for the next meeting, group members are to prepare the next level of Function 1-4 (Manipulate), using gas as a basis.

LEVEL ONE





RECON Meeting Summary
May 26, 1986

Attending: Duncan Hitchens, Gloria Johnson, Oran Nicks, James Magnuson, Bill Moses, Bud Peterson, Ed Rykiel, Ben Scharifker, John Schueller, Peter Sharpe, and Bruce Wright.

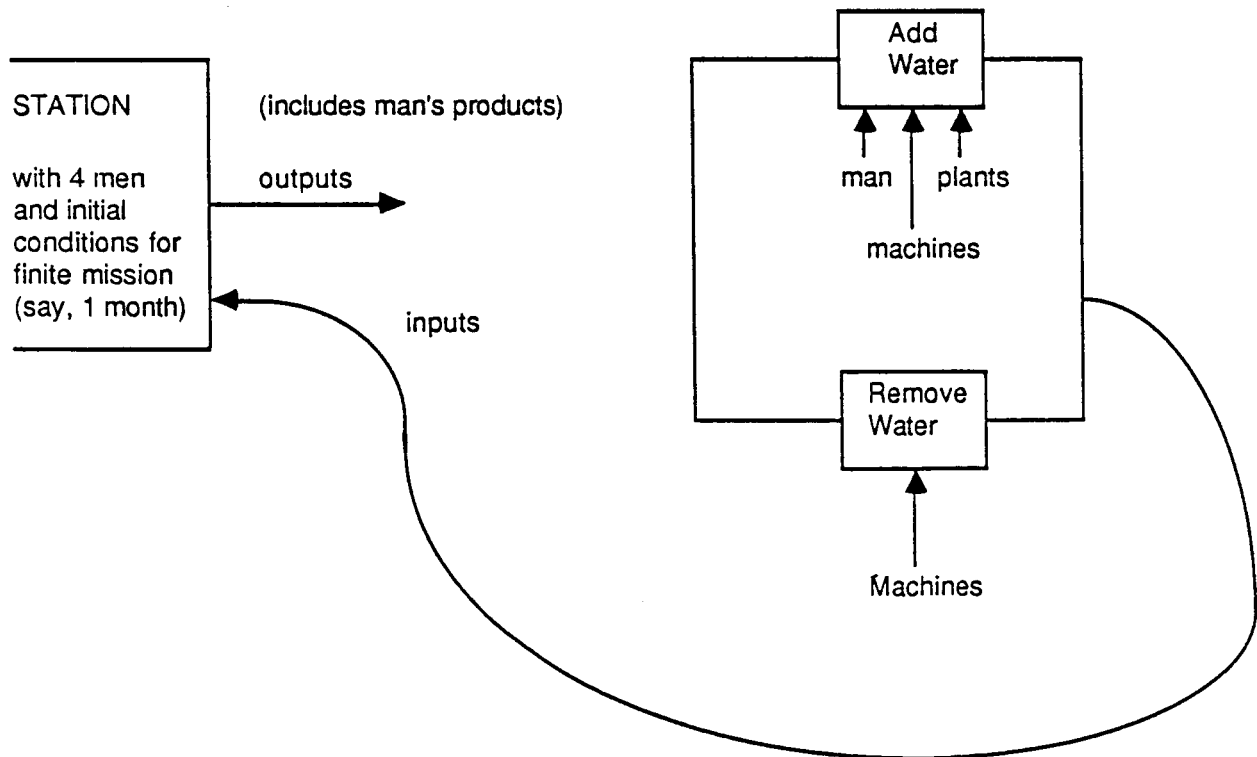
1. Peterson - John Hall's work at Langley.

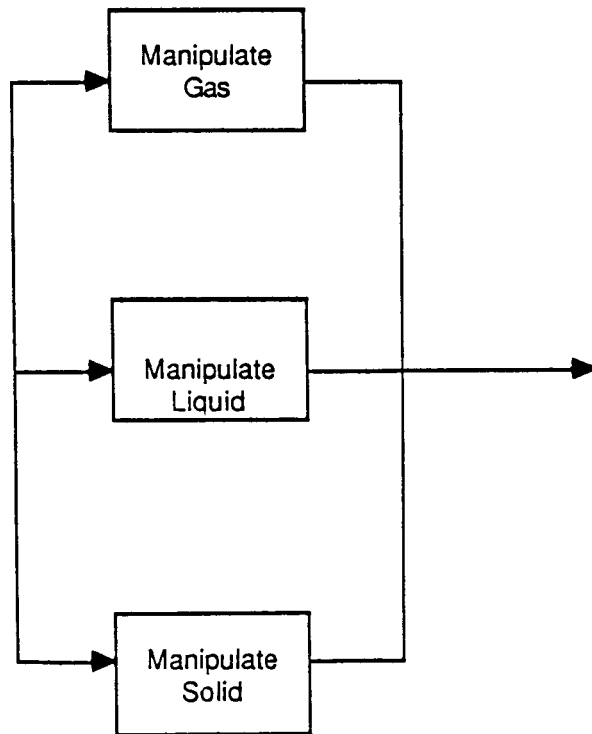
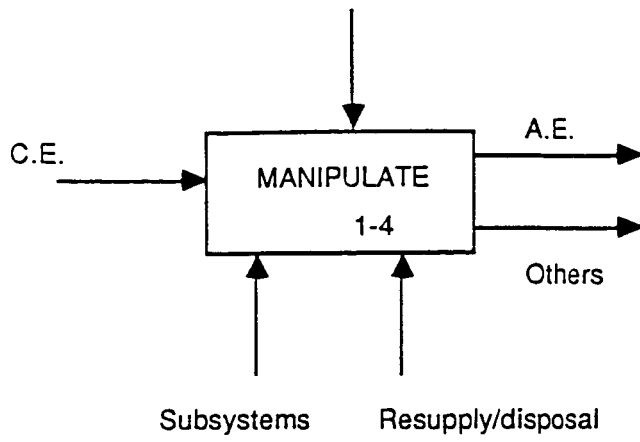
Members had received two papers by Hall for review. Nicks suggested inviting Hall to work with the group. Members decided that they would like to wait until the modeling is finished, so that they will have a basis for working with him.

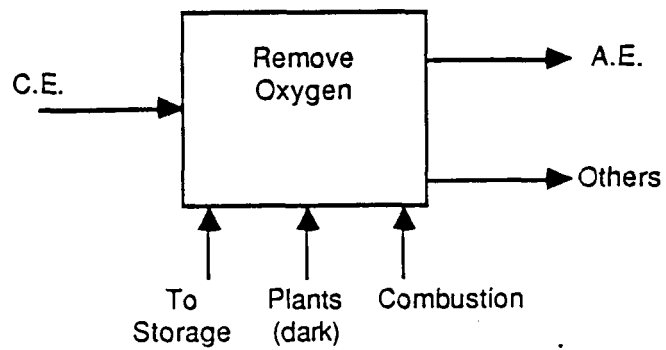
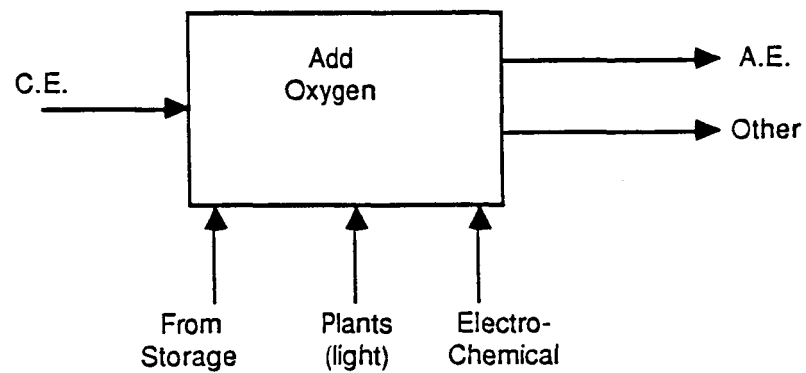
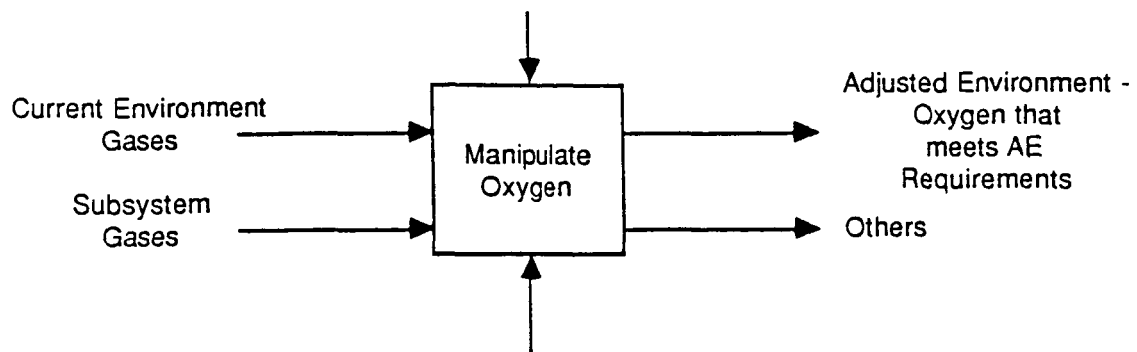
2. Function Modeling

The group decided to use the Space Station Requirements as a basis for the modeling, then put in Hall's data, then work on the combined product.

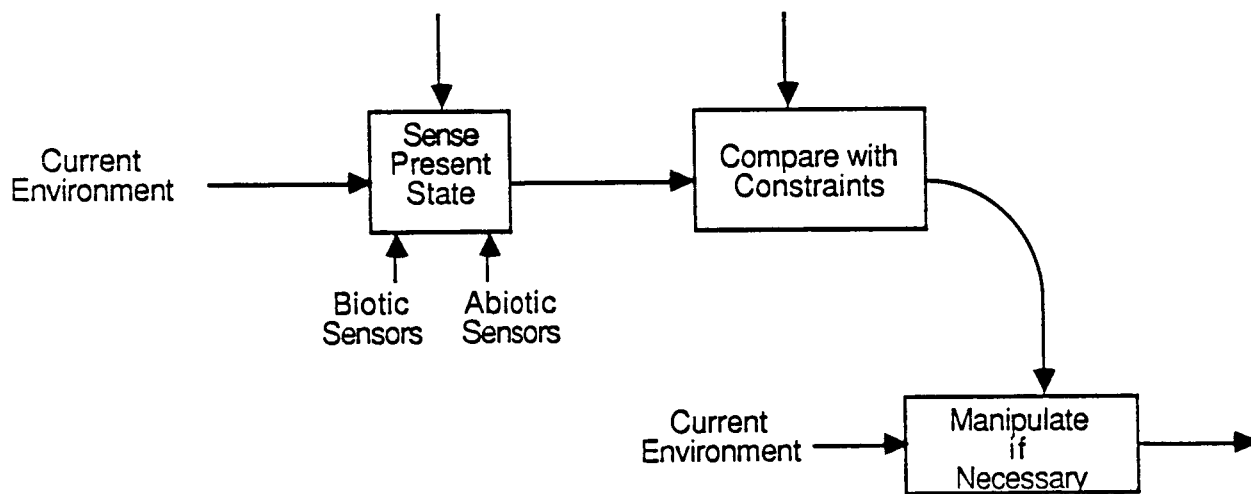
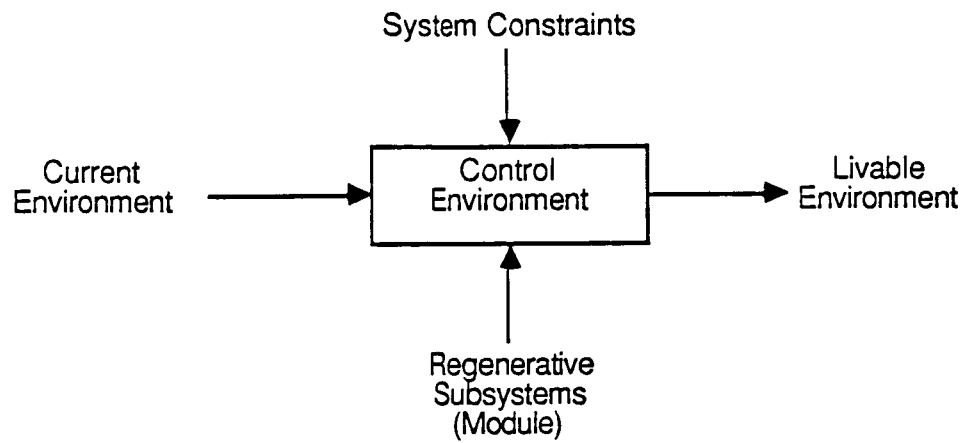
The group defined CONTEXT as the closed life support system, the output/input side. They defined the VIEWPOINT as from the design engineer view, defining functions, assume livable environment exists, and find methods to keep it that way. After some discussion, they decided to leave man out at first, add him in later.

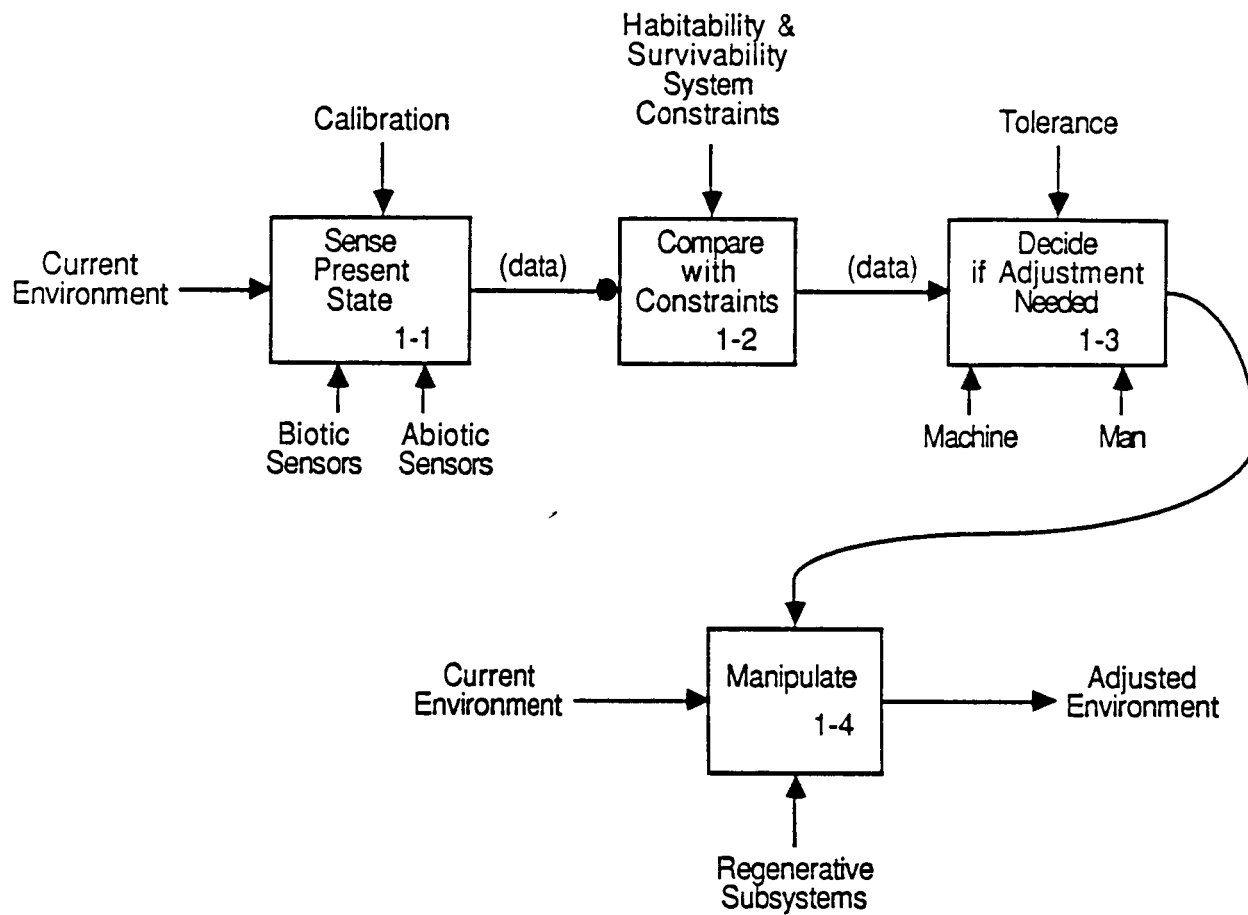






LEVEL ONE





RECON Meeting Summary
June 16, 1986

Attending: Duncan Hitchens, Gloria Johnson, James Magnuson, Rick Mayer, Bill Moses, Oran Nicks, C.O. Patterson, Bud Peterson, Ben Scharifker, John Schueller, Peter Sharpe, and Bruce Wright.

The group worked on identifying the treatments :

1. Waste Treatment - Agricultural Engineering

Wright presented a sketch of waste treatment reactors, which is attached. The group discussed the sketch and asked questions.

2. Mechanical Processes - Mechanical Engineering

Peterson presented the mechanical processes, which is attached.

3. Chemical Processes - Chemistry

Scharifker listed the chemical processes. See attached.

4. AI Update

Rick Mayer visited MCC and discussed the AI workstation with people there, on June 6. He will deliver a proposal to them this week, to illustrate the research that will be done on the machines. He expects an answer and to have the workstations, soon. He talked with the group about getting ready to put criteria for the total system into the KEE.

5. Food

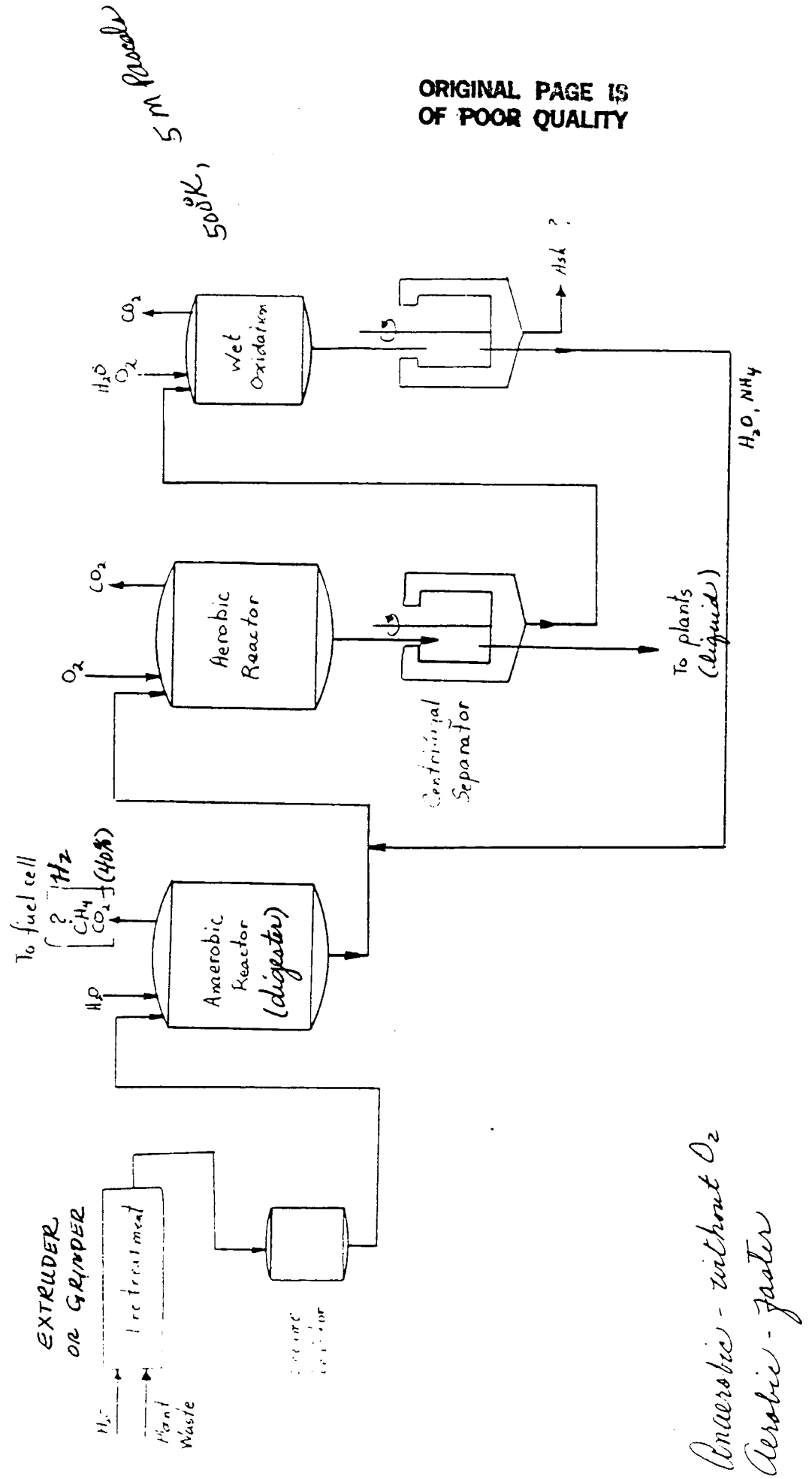
There was discussion about including food processes at this point., and whether to start with processes or to start with the plants. Assignments were made to bring information next week for discussion on food.

Next week's meeting will be on Monday, June 23, in Room 202, ERC, at 1:30 p.m.

Action Items:

1. Wright and Schueller - terrestrial food, diets
2. Patterson - micro-organisms
3. Magnuson - germination of seeds.

Waste Treatment



MECHANICAL PROCESSES

| | Process Efficiency (%) | Power Required (KW) |
|--|------------------------------|---------------------------|
| H₂O Recovery Systems | | |
| Distillation | | |
| - vapor compression distillation | 97 | 0.44 |
| - thermoelectric integrated membrane evaporative | 97 | 0.50 |
| - air evaporative closed cycle | 100 | 1.57 |
| - vapor phase catalytic removal | 97 | 0.16 |
| Filtration | | |
| - multifiltration | 100 | 0.92 |
| - hyperfiltration | 90 | 0.90 |
| - osmosis | | |
| Centrifugal Separation | | |
| - cyclone separation | | |

CHEMICAL PROCESSES

| | IN | OUT |
|---|--|---|
| H₂O Recovery | | |
| solid polymer electrolyte electrolyzers | reclaimed water | O ₂ , H ₂ |
| water filtration | waste | potable water |
| urine electrolysis | urine | CO ₂ , O ₂ , H ₂ , N ₂ , organics |
| CO₂ Processing | | |
| Concentrators | | |
| electrolytic concentrator | CO ₂ | CO ₂ |
| molecular sieve | mix of gases | mix-CO ₂ |
| amine concentrator | diluted CO ₂ | C+O ₂ |
| Reductions | | |
| Sabatier | CO ₂ | C+O ₂ |
| Bosch | | |
| electrochemical eliminator | CO ₂ | O ₂ +? |
| direct CO ₂ reduction | CO ₂ (electricity, light) | O ₂ +organics (formaldehyde +trace organics) |

RECON Meeting Summary

June 23, 1986

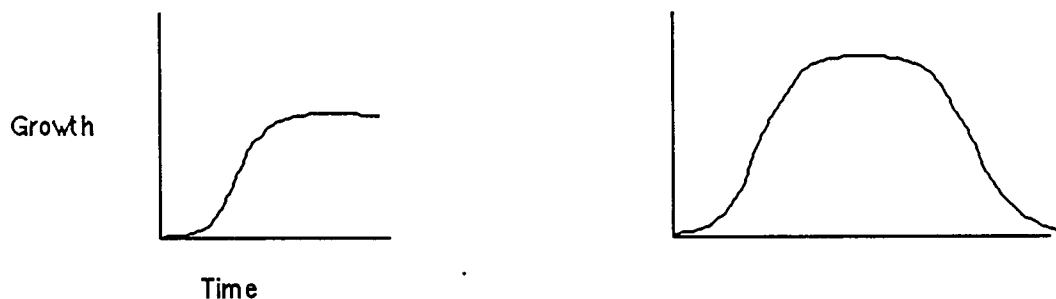
Attending: Duncan Hitchens, Mortada Ibrahim, Gloria Johnson, James Magnuson, Bill Moses, C.O. Patterson, Bud Peterson, Ben Scharifker, John Schueller, Peter Sharpe, and Bruce Wright.

Peter Sharpe presided in the absence of Oran Nicks.

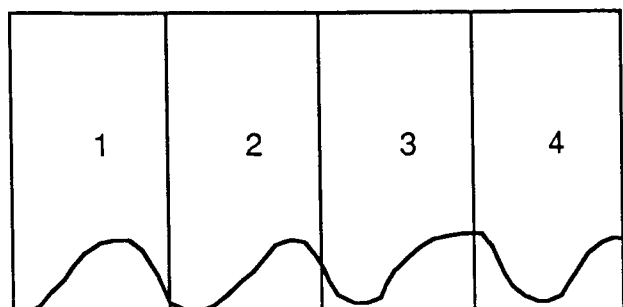
Diets - Bruce Wright

Wright distributed a typical vegetarian diet. After looking at the diet, the group discussed dividing it into three groups: (1) never grow, (2) intermediate, maybe and (3) good, very possibly.

He talked about cropping system management, and the area needed. Ordinary growth curves are:



Would need to split the plants into overlapping growth stages, planting at intervals to keep a regular harvest rate:



Plants have different growth rates. Will need to optimize the use of area. Need to know how to decide when to plant. Take into consideration the carbon balance exchange.

He mentioned the possibility of yeast extracts (like Vegemite) which are rich in amino acids and sprouts, which are rich in carbohydrates.

The group discussed various protein sources, including rabbits, fish, insects and birds (which produce eggs).

Microorganisms - C.O. Patterson

There was a lot of activity in the 1960's, but has been very little since, so information is 20 years old.

Space Station Crew will consume 2 lbs O_2 /day/man

or 25 liters O_2 /man/hour - if on a low protein, high carbohydrate diet.

Chlorella - a green algae - weed of the algal world

MAX RATE photosynthetic, possible rate of gas exchange:

--> 45 l O_2 /kg/hr

MAX steady growth rate:

--> 22 l O_2 /kg/hr

Volume of culture material required = 10gm/l in 100% incoming light

2.3 kg cells = 230 l algal suspension = 300 gal/man for gas exchange, or

500 l volume, including machinery, per crew member.

CO_2/O_2 exchange ratio depends on source.

$CO_2/O_2 = 0.9$ (reduced N source)

$CO_2/O_2 = 0.8$ if N is provided organically - Use form of nitrate to vary.

Temperature: Plain *Chlorella* requires 25°C. *Chlorella* TX 71105, *C. Sorokiana* is a high temperature variety, grows in 39°C (103-105°F).

Illumination - 400-700 nm

1. solar - filter through glass, used as an ultraviolet screen, depending on thickness of glass
2. artificial - (a) incandescent, tungsten filament - infrared - produces heat - efficiency of light production is low; (b) fluorescent - less light, fragile, diffused, toxic gas at breakage, need for bulb replacement.

Light possibilities :

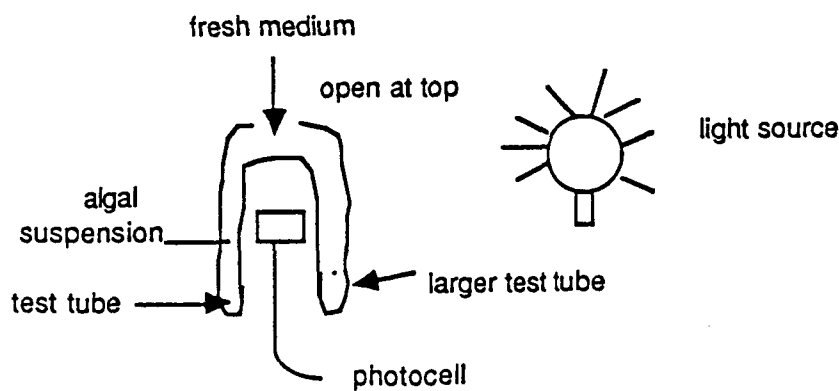
1. in tank, would have to circulate for all cells to receive light.
2. circulate in tubes, past light.
3. immerse lights in the tank.
4. encircle with light, stir.

Need 10-11 kg/man/continuously.

Using light/dark periods will up the volume of algae needed. Might use water jackets, solve the heat problem.

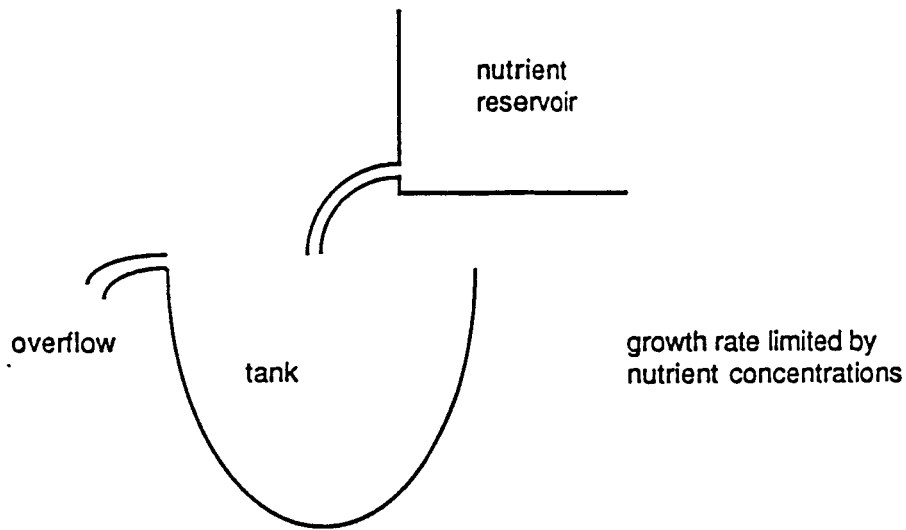
Vessels

1. Turbidostat



2-7 doublings/day - mass
2.3+2.3- plain Chlorella
2.3x9 - TX 11705

2.



Food Production

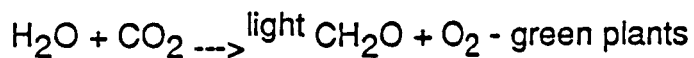
Chlorella -

40-50% pyridian
20-30% lipid

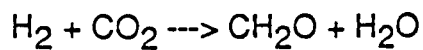
high protein, high fat diet -
20% protein for humans

Cut it, process it, etc. - grow brine shrimp, daphnia, feed them to fish
Blue greens are 50-60% protein.

1. Photosynthesis



2. Chemosynthesis - chemoautotrobes, hydrogenomas



Eat H_2 , scrub CO_2

Photo-split $\text{H}_2\text{O} \longrightarrow \text{H}_2 + \text{O}_2$ (Feed H_2 to algae)

Power requirements drop 1/2 - 1 kw for mixed, 10-20 l/man - food + O_2

15-17% protein - gray crumb

Less known about engineering details.

Next week's meeting will be on Monday, June 30, in Room 202, ERC, at 1:30 p.m.

Action Items:

1. Hitchens - report on hydrogenomas
2. Magnuson - seed germination
3. Wright, Schueller, Garcia - Process alternatives for algae. Begin to look at space, H₂O requirements for plants.
4. Peterson and Moses - How long will 20 l liquid O₂ last? Weight density/gal, resupply baseline, for comparing economics of supplying or resupplying O₂.

Table 1. Selected Plant Used By Practicing Vegetarians

| Legume | Cereal | Fruit | Vegetable | Miscellaneous |
|------------|--------|------------|---------------|--------------------|
| Peanuts | Rye | Orange | Potato | Mustard spice |
| Chestnuts | Wheat | Grapefruit | Collards | Nutmeg |
| Walnuts | Corn | Lemon | Rhubarb | Calery seed |
| Almonds | Oats | Apple | Carrots | Sesame Seed |
| Soybeans | Rice | Strawberry | Cabbage | Oregano |
| Split Peas | | Peach | Asparagus | Sunflower seeds |
| Beans - | | Pear | Green lettuce | Mint |
| Navy | | Watermelon | Spinach | (Active Dry Yeast) |
| White | | Grapes | Calery | Green onion |
| Mung | | | Green pepper | Garlic |
| Lima | | | Green peas | (Baking powder) |
| Kidney | | | Tomato | Parsley |
| Chickpeas | | | Green beans | Onions |
| Lentils | | | Winter squash | (Salt) |
| Alfalfa | | | Beet greens | |
| | | | Cucumbers | |
| | | | Broccoli | |

RECON Meeting Summary
June 30, 1986

Attending: Duncan Hitchens, Mortada Ibrahim, Gloria Johnson, James Magnuson, Rick Mayer, Bill Moses, Oran Nicks, C.O. Patterson, Ben Scharifker, and Bruce Wright.

1. Oran Nicks

Nicks reported on a recent trip to Washington. He said people at NASA Headquarters were interested and encouraging. They need to develop a relationship with engineering and life support people at JSC; they have a high regard for KSC people. They have done some work in hydroponic peanuts and soybeans. It will be possible for 1 or 2 people to go to see them, mid-July, to discuss our project and mutual interests.

GE people are doing paperwork on the hardware and will deliver it in about two weeks. We need a place to put the hardware., as it will require approximately 20'x20' space. Wright will check with Garcia about space in Scoates. GE may fund an effort to use it. Bob Murray can come, give a briefing on its use, and work with the RECON group in a study effort. July 28 or July 25 were discussed as tentative dates for Murray's visit.

2. Duncan Hitchens - Hydrogenomonas Eutropia

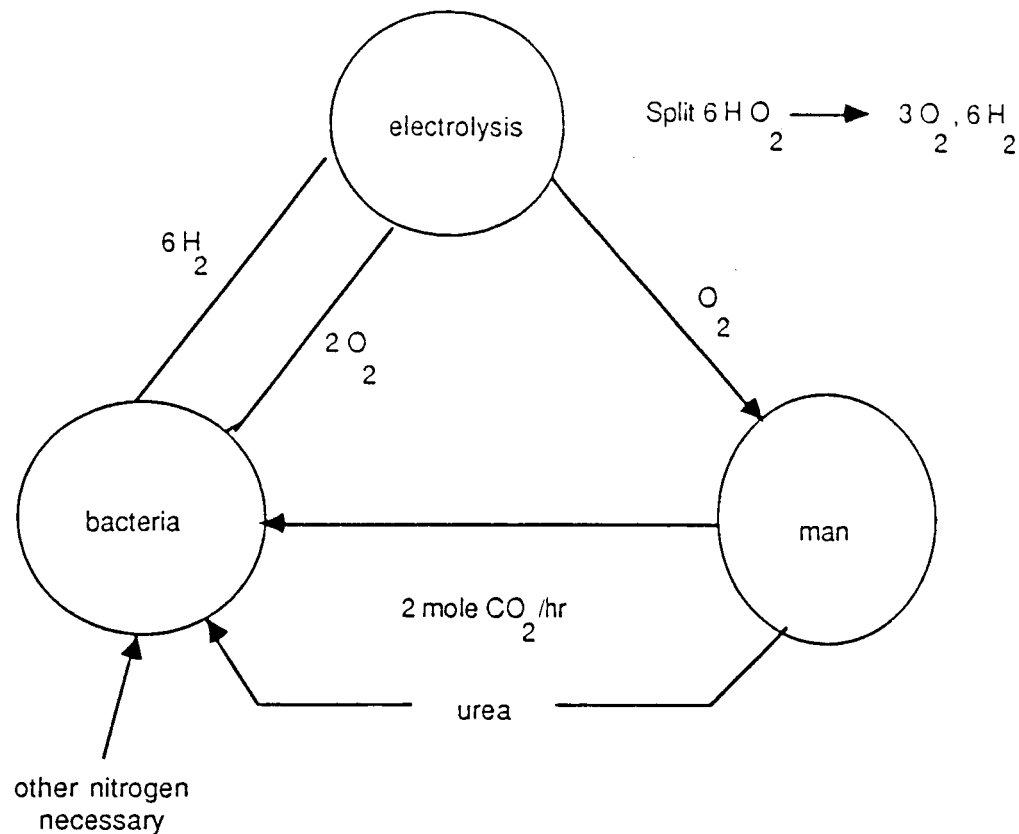
Hydrogenomonas grow on H_2 , O_2 , CO_2 - No illuminated surface is needed.

Gaseous exchange, to support 1 man :

| | <u>algae</u> | <u>bacteria, steady state</u> |
|---------------------|------------------|-------------------------------|
| volume | 100 liters | 20 l |
| power | 10.4 kw/hr | .75 kw/hr |
| illuminated surface | 12m ² | -0- |

Convert all CO_2 of one man back into food - O_2 and H_2 - splitting H_2O chemically

80% of the power supply is preserved.



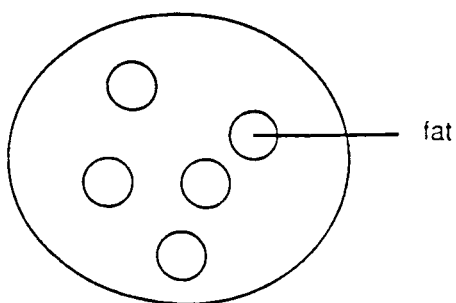
Volume - continuous culture methods (self-regulating, steady state)

20 l ---> .72 kg/day of single cell protein

Problems

1. Single cell protein is not palatable.
2. Cultures studied were in small volumes - scale up, control is less.
3. Cultures must be regulated closely.

Under certain conditions, cultures store fat as PBH, a polymer used in biodegradable plastics.



There was discussion on the use of solar power for photovoltaic - solar illumination would drop power requirements; the question is cooling.

3. Bruce Wright - Single Cell Protein Processing

Wright used soy protein as an example.

Extrusion - would get different crunchy textures to mix with a carbohydrate source, flavors, etc.

Spinning - protein isolate pressed through holes into acidic mixture, solidified, filaments or fibers cemented together.

There is a need for research results in industrial microbiology during the 20 years since NASA's work in the 1960s. Work has been done by firms in the need for more modern techniques for power requirements, handling large volumes of micro-organisms (pharmaceuticals, alcohol), plastic production (ICI, Upjohn, Dow, Merc-Sharpe-Dome, Coors).

4. James Magnuson - Alfalfa Sprouts

Magnuson showed the group a standard food tray which his group developed under a NASA contract as a Shuttle food pack, and flew as a demonstration. The trays are used to grow alfalfa sprouts. Put water in, get sprouts out, with no waste products. The seeds are in the packet. Use a syringe to add water, sprouts are ready in three days. They are grown in a flat of 16 trays (64g of seeds), started at intervals to provide a consistent supply.

Input - 16 packs, 4g seeds each - 3 days - non-photosynthetic, use cabin air.

64g seeds
560g water
624g fresh weight

Air - 216 liters cabin air (80%N, 20%O₂)

Power - 252 watt hrs or .252 kw/hrs

Output - 15,120 joules

5. Mortada Ibrahim - Density figures

55 gal O₂ at 100°K will last a 4-man crew for 50 days.

| Temperature °K (°C) | $\rho_{O_2} (kg/m^3)$ | $\rho_{N_2} (kg/m^3)$ |
|---------------------|-----------------------|-----------------------|
| 70°K (-210°C) | 1216 | 868 |
| 100°K (-183°C) | 1088 | 746 |
| 150°K (-123°C) | 672 | 300 |

The group discussed the use of the AI software. Defined AI as a mechanism for working trade-off problems with various sysytems, some physical meaning by virtue of input to machine. The next need is for a language for communication with the AI machine. For next week, will prepare to resume function modeling, using plants, bio part of the system.

Next week's meeting will be on Monday, July 7, in Room 202, ERC, at 1:30 p.m.

Action Items:

1. Peter Sharpe - present information on higher plants at next meeting.
2. Nicks - set date for Murray's visit
3. All - prepare to resume function modeling.

Sprout System: Inputs + Outputs

Inputs: Seeds: $4 \frac{g}{\text{pak}} \times 16 \frac{\text{pak}}{\text{sprout}} = \boxed{64 \text{ g of seeds}}$

H₂O: $35 \text{ g} \times 16 = \boxed{560 \text{ g of H}_2\text{O}}$

$\Rightarrow 624 \text{ g of fresh wt}$

$1 \text{ cc} = 1 \text{ ml} = 1 \text{ g}$

Air: Breath = $\frac{1}{2} (500 \text{ ml pack}) \times 3 \text{ rats breaths} = 750 \text{ ml/sprout}$

$(750 \frac{\text{ml}}{\text{breath}}) (6 \frac{\text{breath}}{\text{day}}) (3 \frac{\text{days}}{\text{pack}}) = 13500 \text{ ml/pack growing cycle}$

$(13500 \frac{\text{ml}}{\text{pack}}) (16 \frac{\text{pack}}{\text{tray}}) = \boxed{216 \text{ liters air}}$

Power:

Solenoids: $(.1 \text{ A/sol}) (2 \frac{\text{sol}}{\text{circuit}}) \div .2 \text{ A meters} = .4 \text{ A}$
 $(.5 \text{ A}) (28 \text{ V}) = 14 \text{ Watts}$

$(14 \text{ Watts}) (1 \frac{\text{hr}}{\text{sec}}) (6 \frac{\text{sec}}{\text{day}}) (3 \text{ days}) = 252 \text{ Watt hrs}$

Output Fresh Weight: 624 g

Waste Heat: ~~252~~ ~~Watt hrs~~

$14 \frac{\text{J}}{\text{sec}} \cdot 60 \frac{\text{sec}}{\text{min}} \cdot 6 \frac{\text{min}}{\text{day}} \cdot 3 \frac{\text{days}}{\text{batch}} = 15,120 \text{ Joules}$

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Heat treatment. The heat treatment of food is one of the important processes for the conditioning of food for preservation. This treatment accomplishes many objectives, including inactivation of microorganisms, enzymes, or poisonous compounds and production of desirable chemical or physical changes in foods.

When compared to typical engineering material such as metals or minerals, food is relatively susceptible to thermal degradation. Therefore, to produce nutritionally sound and microbially safe food products, heat treatment should be accurately controlled in order to accomplish its objectives. To assist in this control, the temperature responses of foods subjected to heat treatments are frequently estimated by using empirical or theoretical heat-balance equations.

Heat treatment follows different patterns. It may involve application of heat indirectly, as in a tubular heat exchanger, or it may be accomplished through the direct contact of the heating medium with the food, as in the baking of bread in a hot-air oven. The principal operations involving heat treatment of foods are blanching, preheating, pasteurization, sterilization, cooking, evaporation, and dehydration.

Food forming. Food forming is the mechanical shaping of products to precise shape and form. Basic techniques include extruding (spaghetti); sheeting between rolls, cutting into strips, crosscutting into slices or bars (cheese and candy); sheeting and die-cutting (cookies); stuffing and casing (sausage); molding in metal or starched ties (candy); depositing metered portions onto a rotating surface (chocolate bits); dividing into portions and rounding by rolling over rotating metal surface (bun dough); rounding by rotating portions between belts traveling in opposite directions (meat balls); twisting (dough); layering by depositing one sheet on top of another (candy); layering by multiple folding (pastries); puffing by vacuum (candy); sudden pressure release (cereals), or by formation of gas or vapor in processing (potato puffs); tableting by compacting powdered or granular material in dies by plunger action (confections); agglomerating powdered material (to form larger, more soluble particles) by intermingling in humid atmosphere (instant dry milk).

Food analogs are fabricated from lower agricultural raw materials such as grains, legumes, by-products of food processing such as cheese whey, fish muscle of little or no economic importance, and meat by-products such as bone marrow and low-cost organ meats. Such unlikely sources of protein and other nutrients as grasses, paper, and blood from animal slaughter have been successfully used.

Spinning process. In the spinning process (Fig. 9), based on the Boyer process, protein, usually soya, is solubilized in an alkali aqueous media. The viscous gel-like mass, called dope, is forced through a spinnerette (die) containing as many as 15,000 fine holes each with a diameter of $4/1000$ of an inch. The filaments thus produced are extruded into an acid bath which sets the fiber by coagulating the protein. The fibers, averaging 20 μ m in diameter, from a number of spinnerettes, usually three or four, are gathered into a bundle of 1/4 in. diameter and then a number of bundles are assembled into a "tow" of 3- to 4-in. diameter. The tows are fed into a series of baths, going through rollers at each bath, which squeeze out the salt produced by neutralization. The rolls are set successively at greater speed to stretch the fibers, which imparts the degree of tenderness or strength desired. Elongation of the fibers due to stretching is from 50 to 400%, depending on the protein used.

The first bath washes the fibers, the second incorporates binders such as egg albumin or vegetable gums, and the third, primarily for the incorporation of fat, also includes flavor, color, emulsifiers, and nutrients.

The fibers are next cut to size and compressed into the desired shape — a ham slice, chicken slice, beef cubes, and so on.

This process is the basis for most of the meat or fishlike analogs currently available. These include the breakfast sausages and bacon strips that have gained significant consumer acceptance.

Thermoplastic extrusion process. The second basic process for the production of analogs is the thermoplastic extrusion process. Not only is the process itself more economical, but lower cost protein such as soya flour with 50% protein may be utilized, as opposed to protein isolates of 90% protein content which are required for the spinning process.

The equipment required for this process is essentially that developed for the production of snack foods.

OIL & PROTEIN PRODUCTS FROM SOYBEANS

Oil extraction. The basic processing of soybeans consists of separation of the oil and meal. The equipment used varies considerably from plant to plant although the general process, solvent extraction of the oil, remains the same. Older, obsolete methods used either continuous screw presses or hydraulic presses to squeeze out the oil. Solvent extraction has almost universally been adopted because of its efficiency and low operating cost.

The steps involved in the solvent extraction of soybeans are outlined in Fig. 3. Storage of soybeans in elevators or silos is included as part of the processing since it ensures a continuous, year-round supply of beans for processing without the day-to-day price fluctuations of the commodity market. The soybeans, prior to storage, are cleaned and dried to 12-14% moisture for improved stability until processed.

Preparation. The processing operation consists of preparation, extraction, and meal-finishing phases. Preparation for extraction consists of steam-conditioning the beans, cracking, dehulling, and flaking. Cracking the beans into small particles, usually six to eight pieces, loosens the hulls from the soybean meats and assists in the flaking operation. Corrugated rollers are used for the cracking operation. Dehulling or separation of the hull material from the cracked meats is necessary to increase extraction efficiencies. Dehulling is performed by a combination of air aspiration, screening, centrifugal separation, and density separation methods. Flaking the cracked, dehulled soybean meats facilitates the extraction process by disruption of the internal cellular structure of the bean and by allowing better contact of the extracting solvent with the internal parts of the seed. Flaking is done by heating and steaming the cracked meats and passing them through differential roller mills. The resulting flakes are paper-thin (0.25-0.40 mm).

Extraction. This operation consists of washing the flakes with a petroleum solvent, usually hexane. The solvent is kept near 50°C during extraction to speed the solubilization of oil from the flakes into the solvent. The oil-laden solvent, called micella, is then separated from the flakes and distilled for recovery of the solvent for further use. The crude soybean oil is then pumped to storage tanks for further processing or to be sold as crude soybean oil.

Finishing. The solvent-wet, defatted flakes are desolventized by steam and heat. The

Soybean protein products. The soybean protein products are prepared from the extracted meal. Three distinct product types are prepared: soy

flour and grits, soy protein concentrates, and soy protein isolates. These are used both in foods and in nonfood applications.

Isolates. Soy protein isolates are the purest form of soy proteins marketed (90% protein minimum). The isolates are prepared by solubilizing the protein present in the grits by using mildly alkaline solutions, separating the protein solution from the fibrous residue by centrifugation or filtration, and acidifying the protein solution to precipitate the protein as a curd. The curd is recovered, washed, and resolubilized, and the spray is dried into a fine flourlike powder.

Textured proteins. Each of the soybean protein products can be used to form textured soy proteins. Textured soy proteins have a meatlike texture and appearance when hydrated and can be used for extension of ground and comminuted meats (such as ground meat and bologna) and for the preparation of simulated meats. When used as extenders, the textured proteins increase yield, aid in binding of meat constituents, and improve emulsion stability.

Two general processes (with variations) are used for texturizing soy proteins: extrusion cooking and spinning. Extrusion cooking consists of moistening the protein, working the doughlike mass under high temperature and pressure, and forcing the cooked mass through an orifice, which permits the heated compressed mass to expand. The product is then dried and sized. Colored and flavored extruded soy protein products are prepared by addition of these additives either before or after extrusion. Imitation bacon bits based on extruded soy flour are widely marketed.

Soy protein isolates are required for spinning. Spun proteins are somewhat more adaptable to simulated meat production than extruded proteins. Spun proteins are produced by solubilizing the isolates in an alkaline solution and forcing this solution through a multiholed die immersed in an acid bath. The solubilized protein immediately coagulates in the acid bath, forming a continuous fila-

ment. The filaments are stretched to orient the protein molecules within the filament. Toughness of the filaments is dependent upon the degree of protein orientation. Filament diameters are approximately 0.003 in. (0.076 mm). Groups of filaments when combined with egg white, flavors, and colors, followed by compression and heat setting, form products such as ham, chicken, or beef. See

RECON Meeting Summary July 7, 1986

Attending: Duncan Hitchens, Gloria Johnson, James Magnuson, Bill Moses, C.O. Patterson, Bud Peterson, Ben Scharifker, John Schueller, Peter Sharpe, Harold Slater, and Bruce Wright.

Bud Peterson presided in Oran Nicks' absence.

1. GE Equipment - Peterson

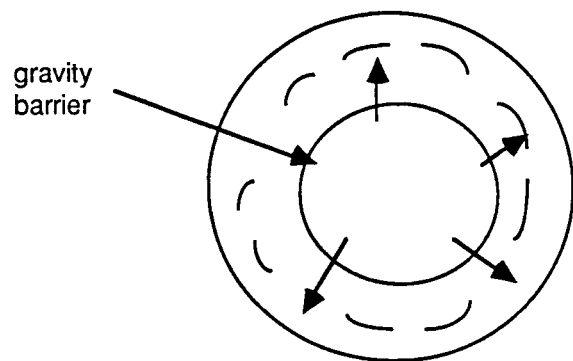
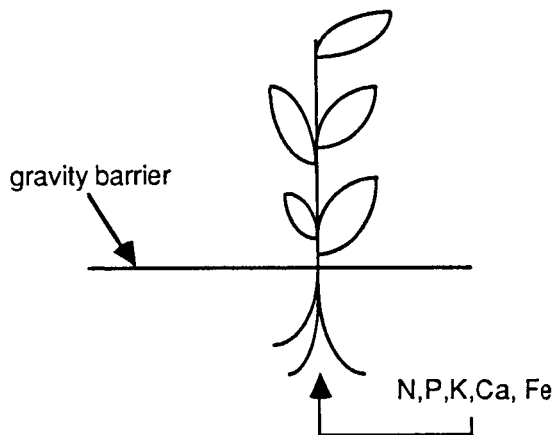
Peterson talked with Bob Murray at GE about space and connection requirements for the hardware. There are three possibilities for space: (1) Mechanical Engineering, (2) Agricultural Engineering, and (3) Peter Sharpe suggested there might be space at the new Food Protein Research Center. Food Protein is located on the West Campus, while the other two would be more accessible to the group. Gloria will circulate copies of the Operation Manual, which gives specs on the hardware.

2. Higher Plants - Peter Sharpe

Plant needs:

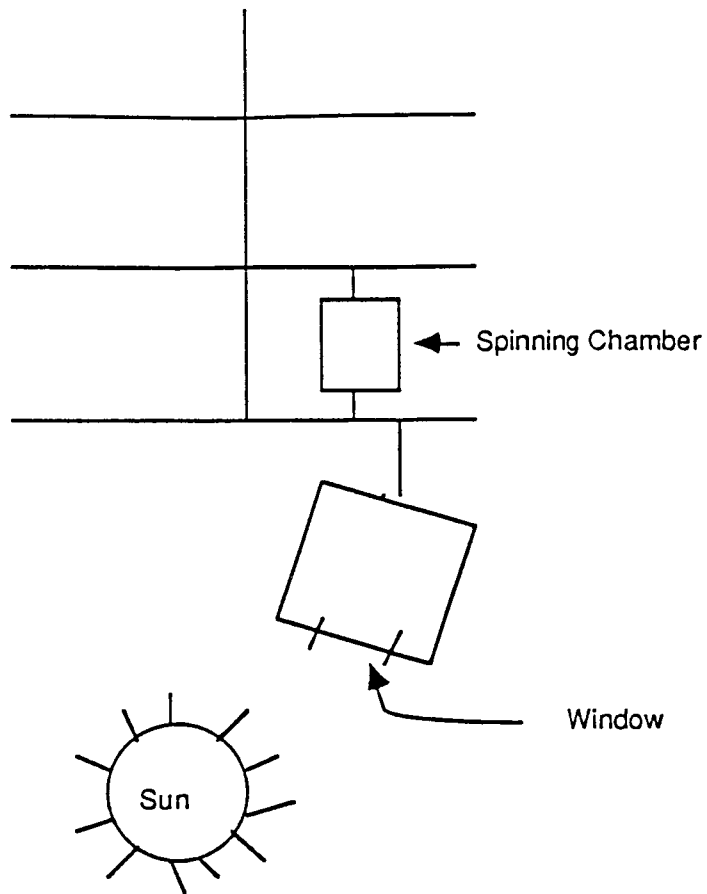
- light - 2% efficient with solar radiation
- water - recycled through the plant
- mineral nutrients - N, P, K, Ca, Fe
- temperature - 30-35°
- gravity - need a gravity barrier of some sort
- gas exchange - CO₂, O₂, N₂

Gravity barriers:



Growth Chamber

Space Station, with spinning chambers:



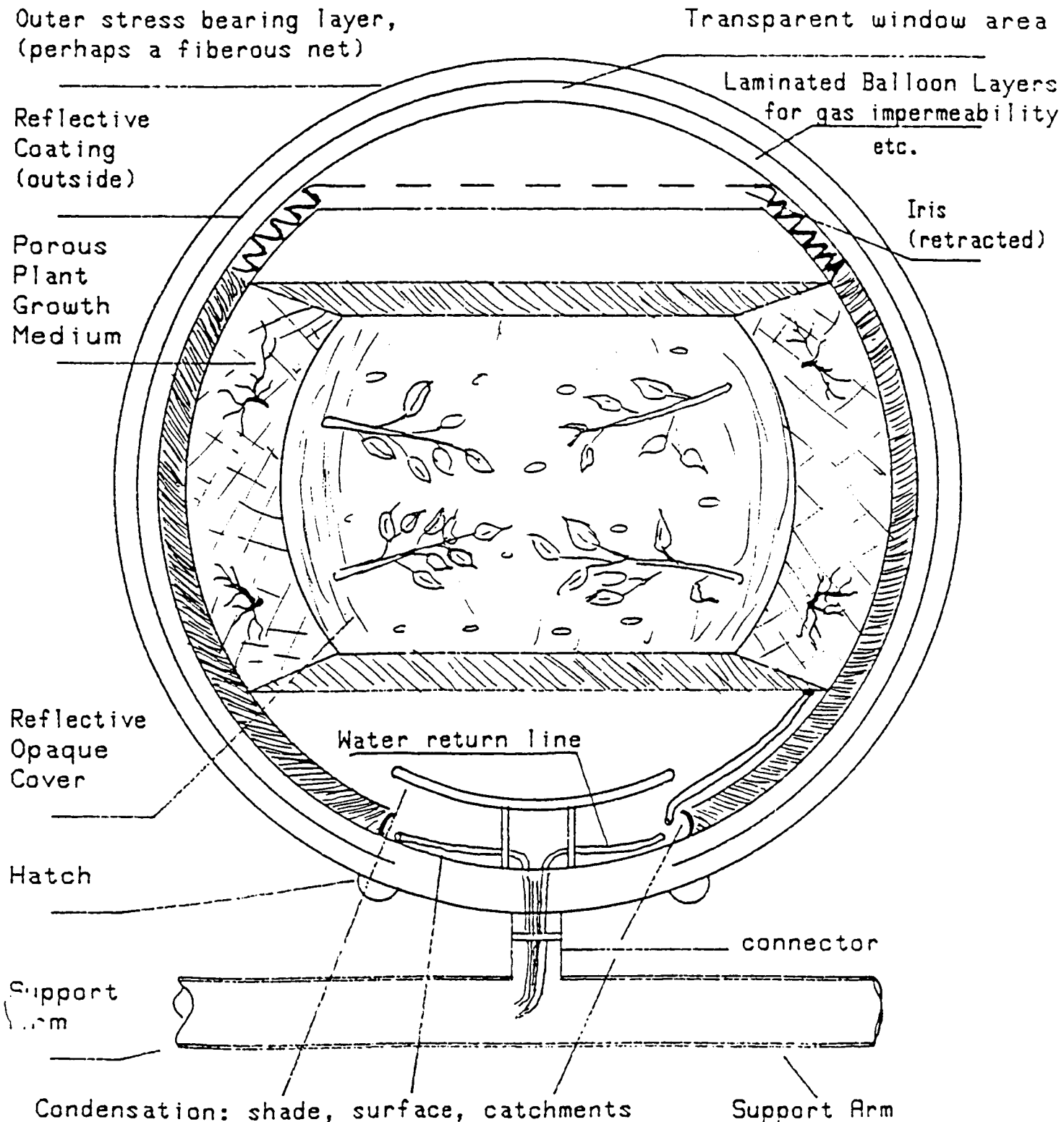
John Goeschl developed a model utilizing a spinning chamber (see attached sketch). There are problems with using spinning chambers: (1) rotary joints with airtight seals are unreliable, and (2) movement is undesirable because it causes wear in other areas. What is needed is a capillary based, passive system.

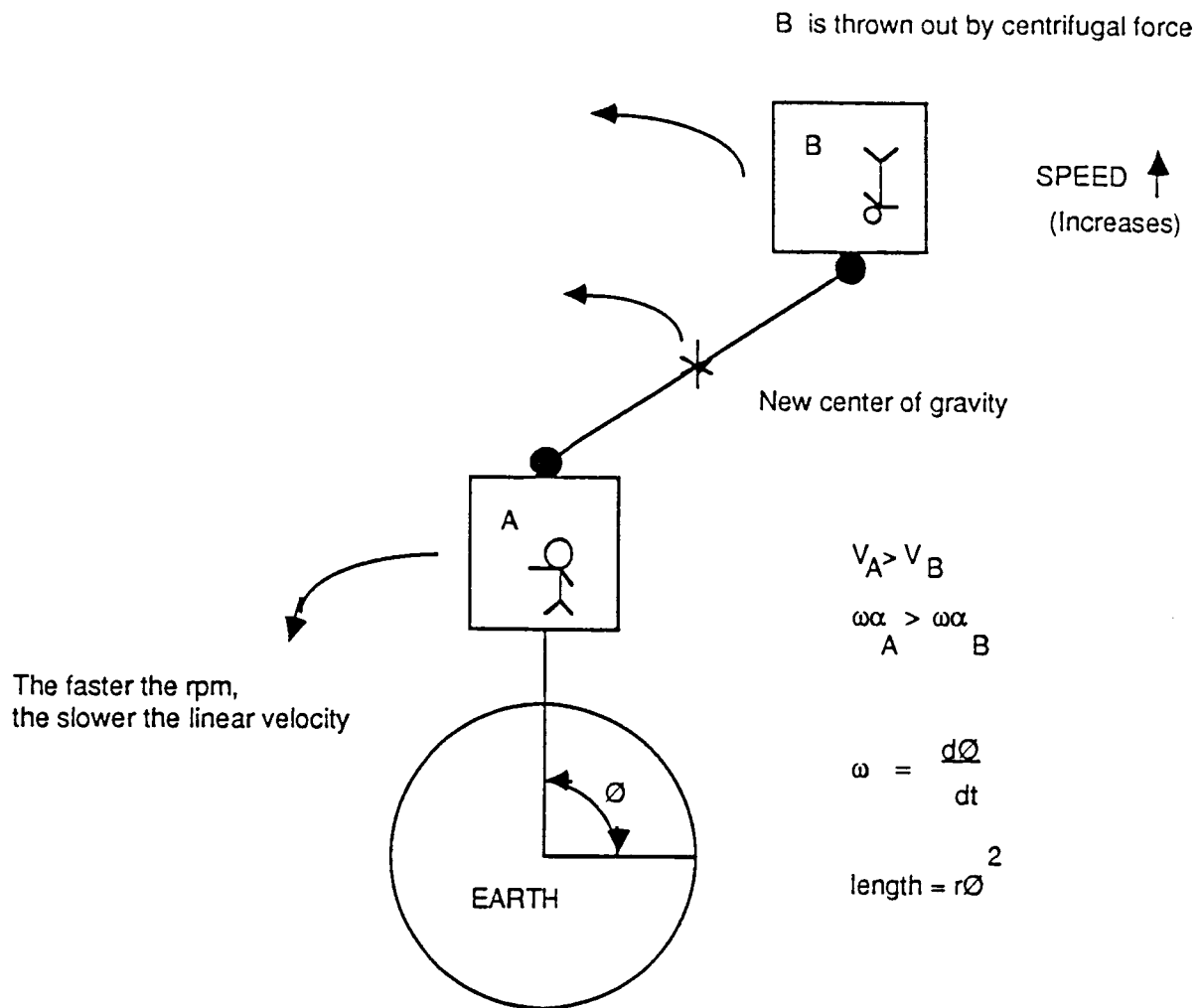
3. Tethered Bodies - Bruce Wright

Wright did some work at NASA on tethered bodies, which use devices on a cable to drag through space, measure air flow, study flow characteristics, and create an artificial gravity.

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"BALLOON" for growing plants in space. Preliminary Drawing: John D. Goeschl





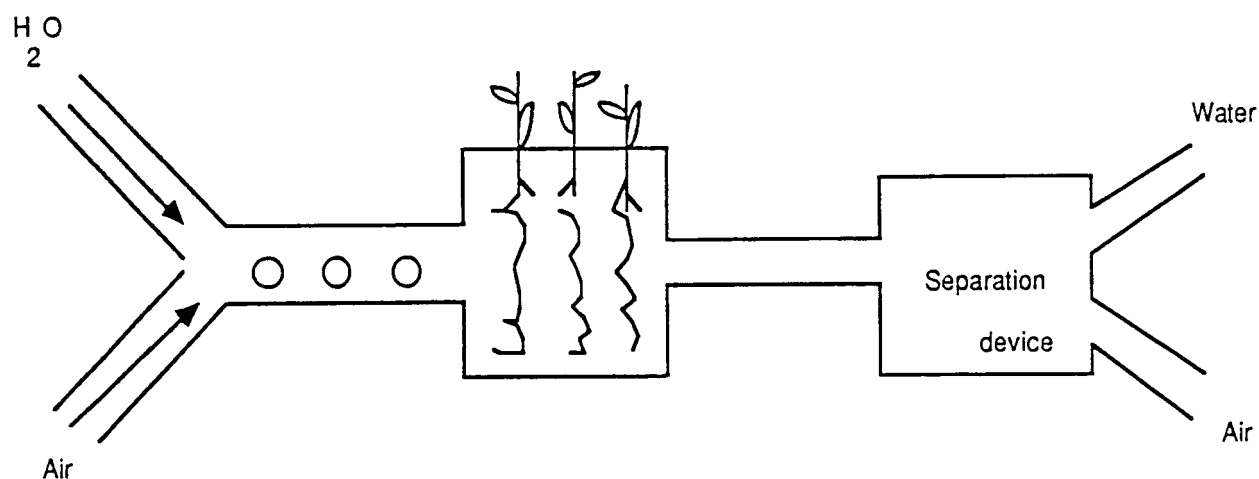
The group discussed the dangers of being restricted to earth orbit.

4. Plant Roots - Bruce Wright

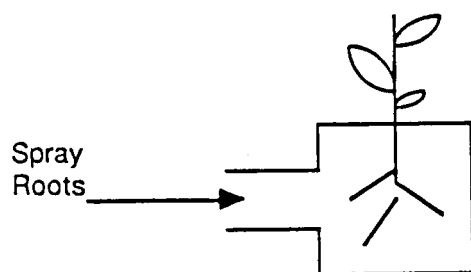
Plant roots need air, water and nutrients. There are different ways to provide for the needs of both plant and roots without mess.

1. Mixed Phase

Air bubbles in water



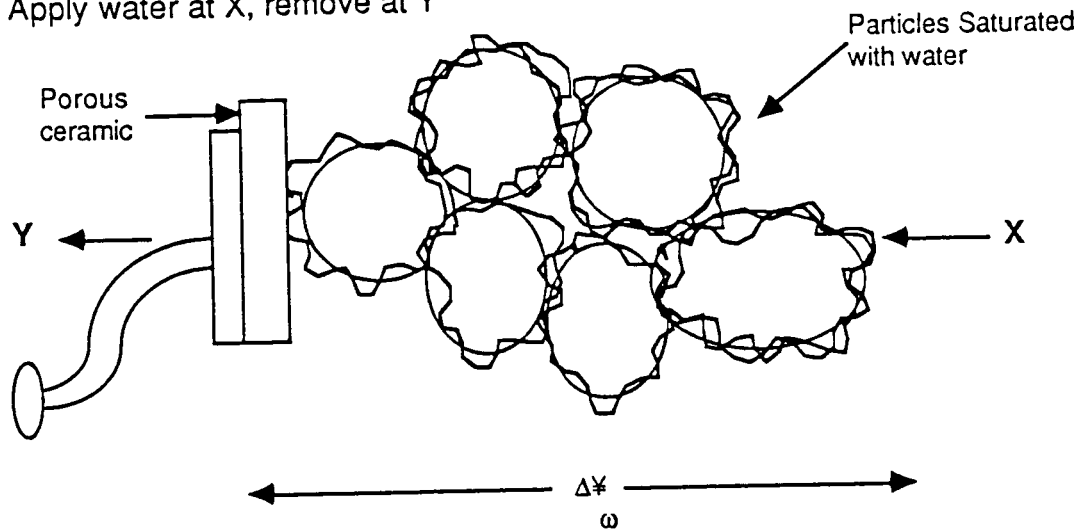
Water bubbles in air (spray)



2. Separate Phase

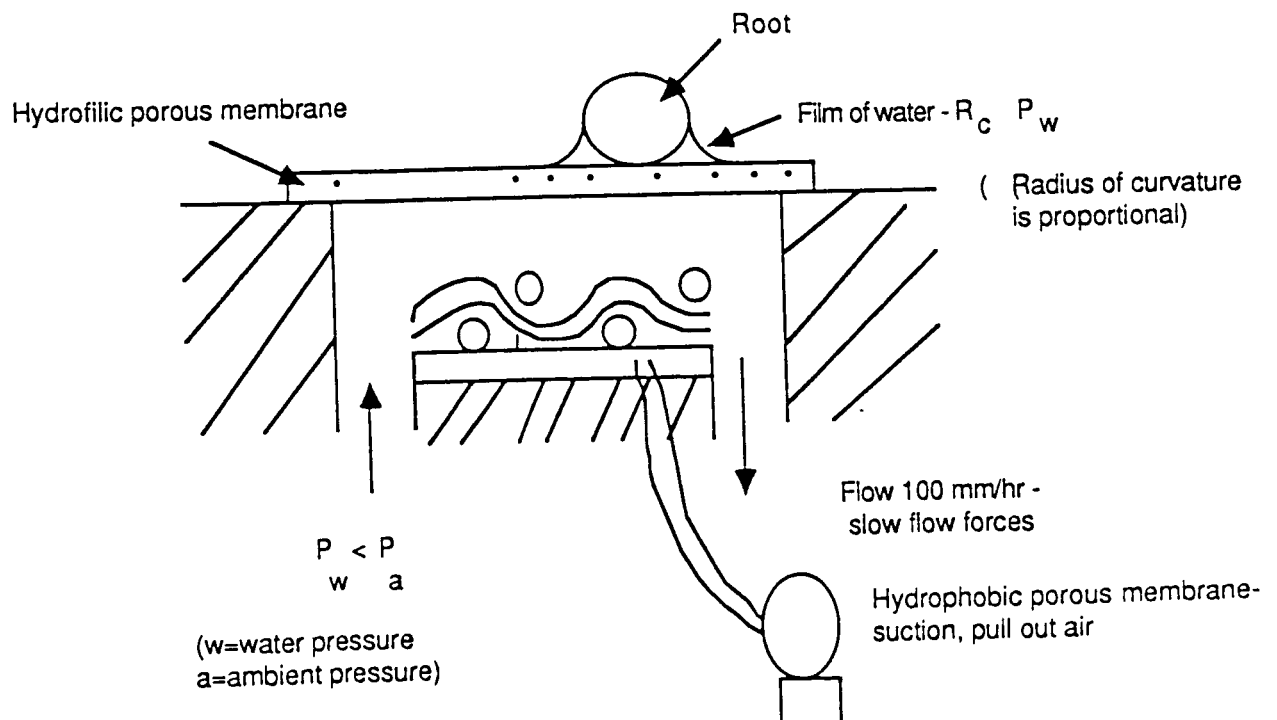
Porous medium (soil) - Negative potential-recovery system

Apply water at X, remove at Y



Water quotient, gradient gravity flow - pressurized

3. Porous membranes



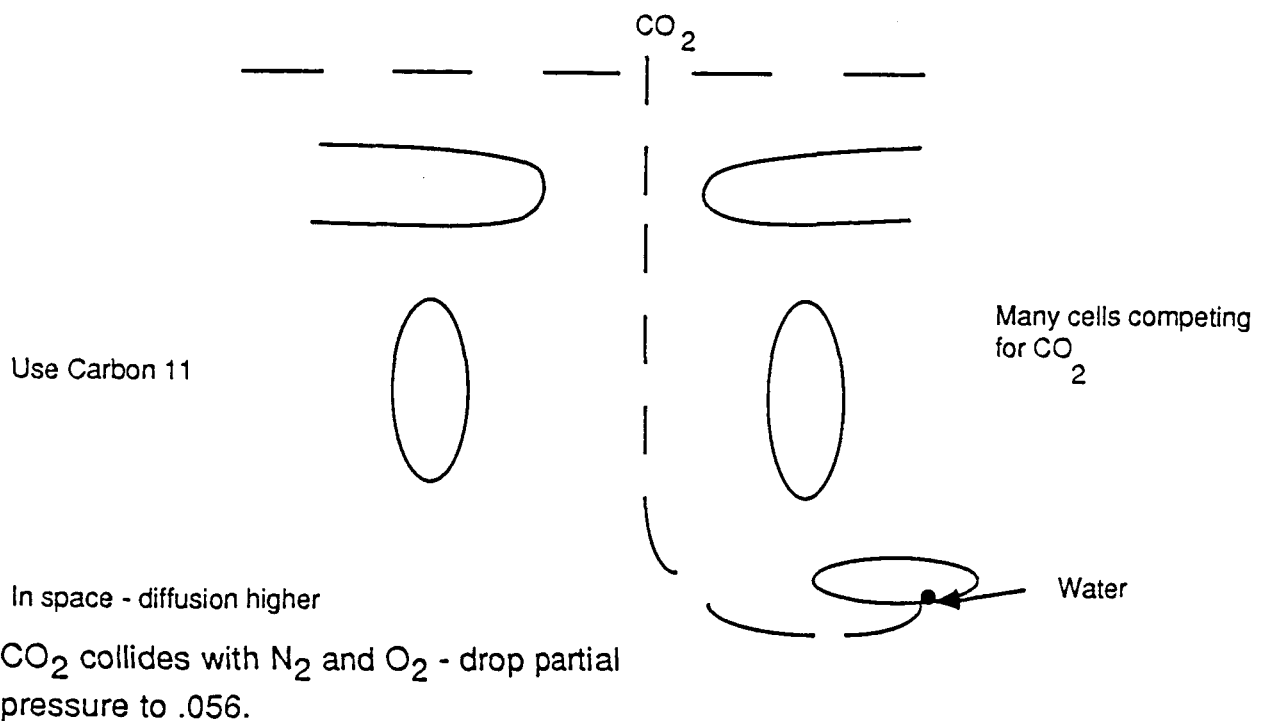
Light response will not work for roots.

Ionization - Develop an electronic field, with a negative charge, make roots go into medium and take hold. Orient the seed so the root radical will hit the soil first.

5. Gas Exchange

CO₂ 250-700 ppm on earth for plant growth
average is 350 now, is increasing.

Raise CO₂ level, increase growth rate, yield. Use high level CO₂ plants.



| GAS | ATM % | PARTIAL PRESSURE | NEW PARTIAL PRESSURE |
|------------------|-------|------------------|----------------------|
| N ₂ | 77 | 584 mm | -0- |
| O ₂ | 19 | 144 mm | 11.4 mm |
| CO ₂ | <1 | 0.23 mm | 0.38 mm |
| H ₂ O | 4 | 31.8 mm | 310 mm |

RECON Meeting Summary

July 14, 1986

Attending: Karl Aufderheide, C. O. Patterson, Ben Scharifker, Duncan Hitchens, James Magnuson, Albert Garcia, John Schueller, Bruce Wright, G. P. Peterson, Marta McMurray.

C. O. Patterson presided in Oran Nicks' absence.

1. There is a need to do literature searches for more up-to-date material on regenerative concepts. The STAR reference (government documents) are in the library, they are put together by NASA. NASA has a database called RECON. Since we are working with NASA JSC, we might be able to get articles through them.

2. Bob Murray will be here on Monday, July 28. Think about questions to ask him about setting up the equipment, what requirements will G.E. place on the use or upkeep of the equipment. Will the title be passed on to TAMU. Ask him for data records of expected level of operation. Amount of money expected to get it running again, it needs to be calibrated, it is 15 years old. Who will be responsible for setting the equipment up.

Nicks - contact the A&M Development Foundation. They take care of those questions and can give us an idea of what to expect.

- contact Dr. Richardson for space in Protein Lab for the equipment.

There is a possibility of setting it up in the Food Protein Lab. It needs 400² ft. of space minimum. The vacuum pump system may not come with it. Are there any technical or legal reasons why its exhaust should not be hooked up to another system?

3. The JSC Review Meeting is on August 13. Discuss what to say and how to say it and decide who will talk. This will have to be done in the next two meetings 7/21 and 8/4 (7/28 will be taken by Murray's visit).

Ideas of presentation could be what potential applications for Closed Life Support Systems the GE equipment could have. Output of media. Can minerals that come out dry be re-watered and used? Look at systems of Closed Life Support Systems with oxidation on plants and microorganisms.

4. Modeling Activities - Patterson

The information distributed is about 20 years old. There has been some difficulty in locating anything more recent data. That is why literature searches are to be done. The handouts show the kinds of constraints and parameters that can be expected. More detailed than earlier ones. From Gerathewohl: Note there are no requirements for washing water. H₂ conversion into H₂O, etc. Atmospheric requirements for different durations. How to remove various waste products. Chemical O₂ producing systems.

CO₂ removal systems. Effect of O₂ presence on human performance. No such charts exist for plant growth. Ask NASA for this kind of data. Figure 11.16 on Pg. 6 shows the pathways and numbers as to inputs and outputs. Recycling of urine.

From Kammermyre: The Kinds of Atmospheric contaminants trapped in activated charcoal. Aromatics from plants may be a problem as contaminants. What about heavy metals accumulating during recycling, like chromium from the stainless steel. EDTA is known to be used to decontaminate the body of such metals, and could be added to the diet.

Pages 3-6: Algal gas exchanges. Designs and configurations that have been tried. Power requirements and efficiency.

Page 6: Yield vs. Efficiency Curve.

5. K. Aufderheide: Biological Recycling Systems

Protozoa are central to sewage process systems. Recycling is done in a closed system which makes it applicable to a closed life support system in space. The IMHOFF system is characteristic of small cities and towns. The anaerobic tank produces many things. It takes organic stuff into inorganic material, and it is relatively less efficient. The protozoa need O₂ circulated around them. The Activated Sludge System is more aerobic but still puts out smell. Requires mechanical system to stir it. The raw materials gather in mats which are stirred with paddles. The consumption of O₂ and the production of waste materials is big and there is a lot of weight required. The gases that are produced can be recycled to a fuel cell. This is being done now. Certain species of bacteria are associated with healthy output. It is necessary to know how they interact to produce sludge. Need to describe functions that describe plant growth, fermentation tanks, etc. and make sure that what is produced by one system is used by another to keep the balance.

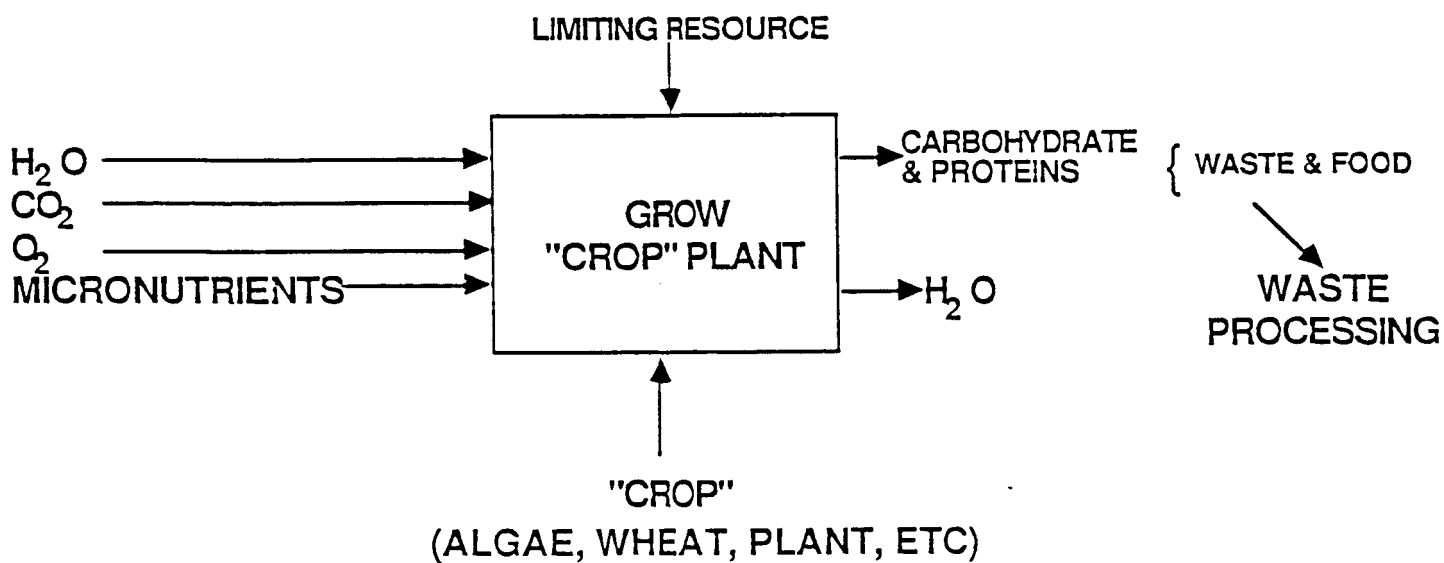
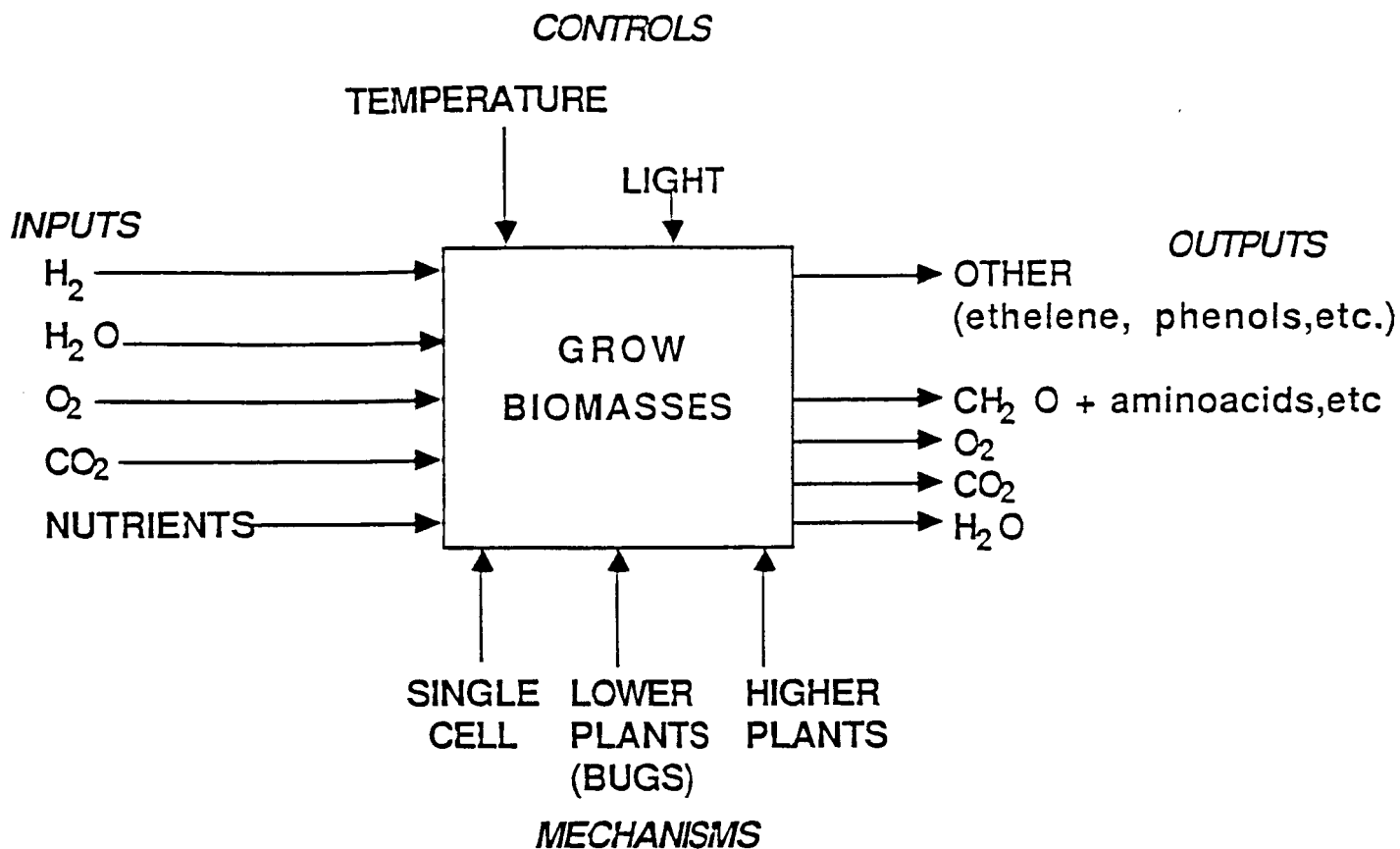
6. Action Items:

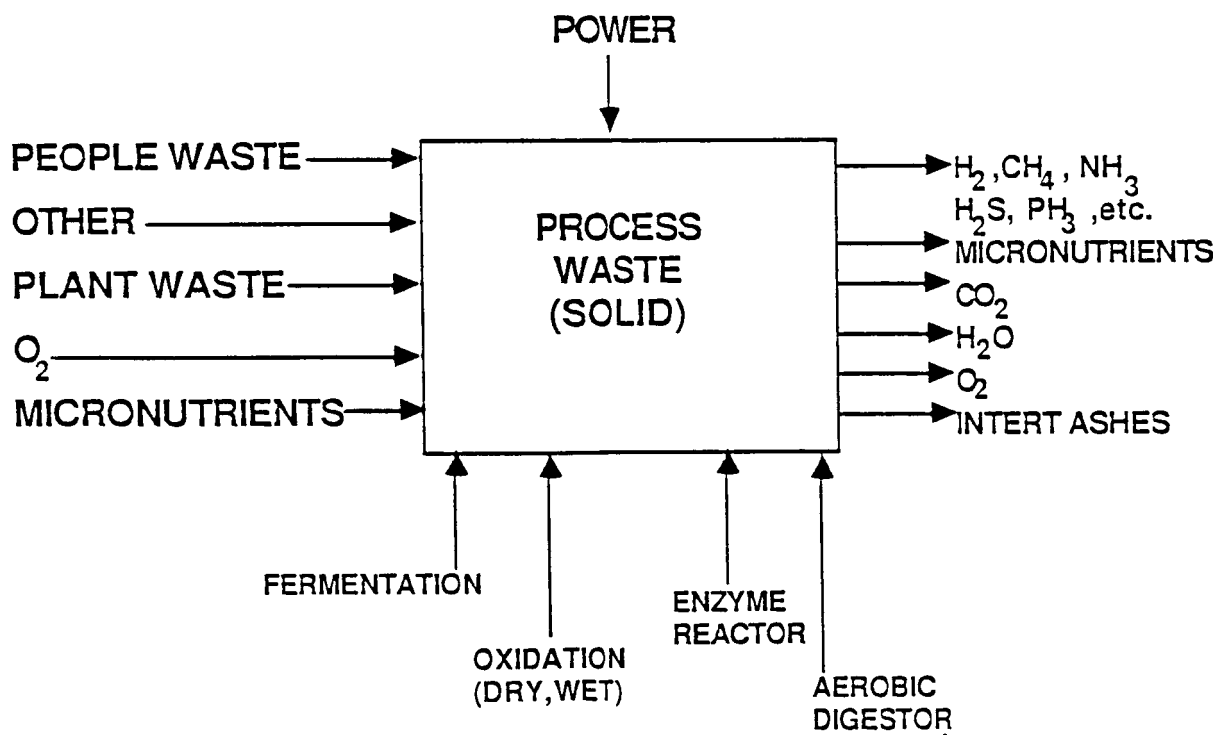
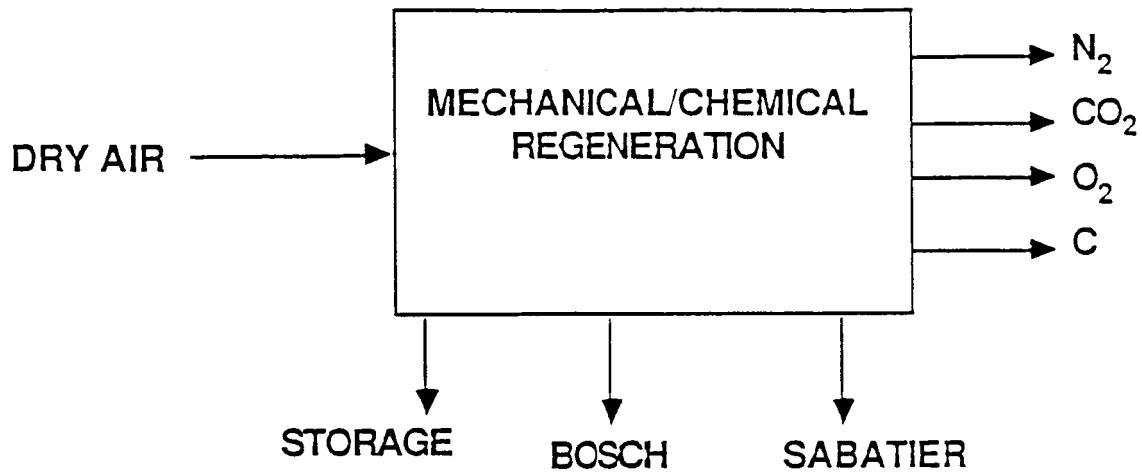
1- Water processing in more detail. Search literature for numbers to be used in the function charts for volume, power requirements, throughput and material processing.

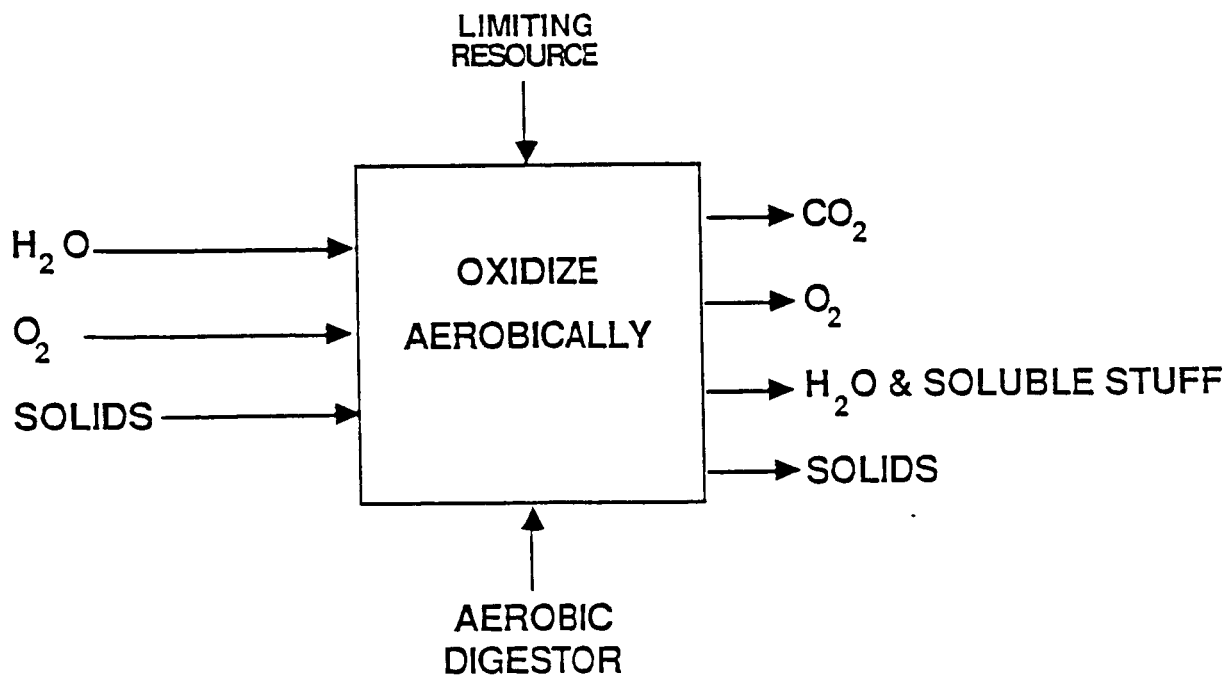
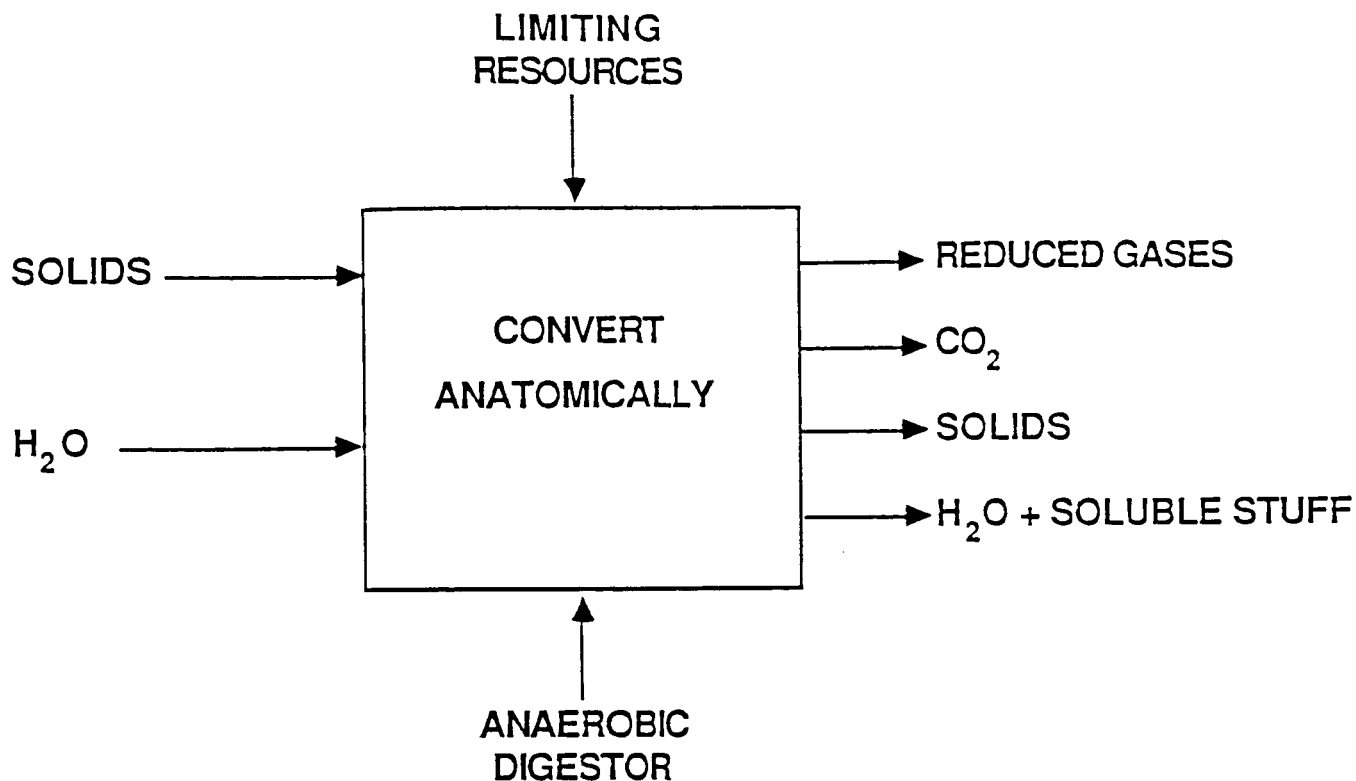
2- Questions for Bob Murray.

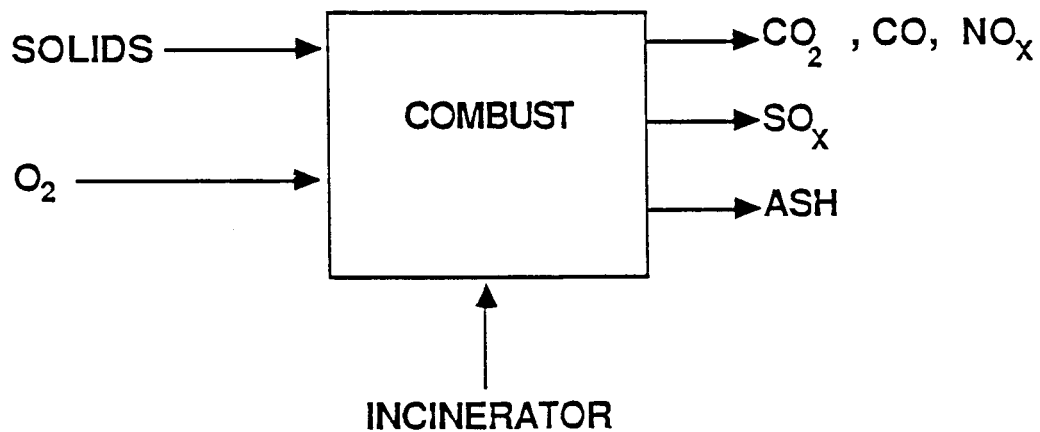
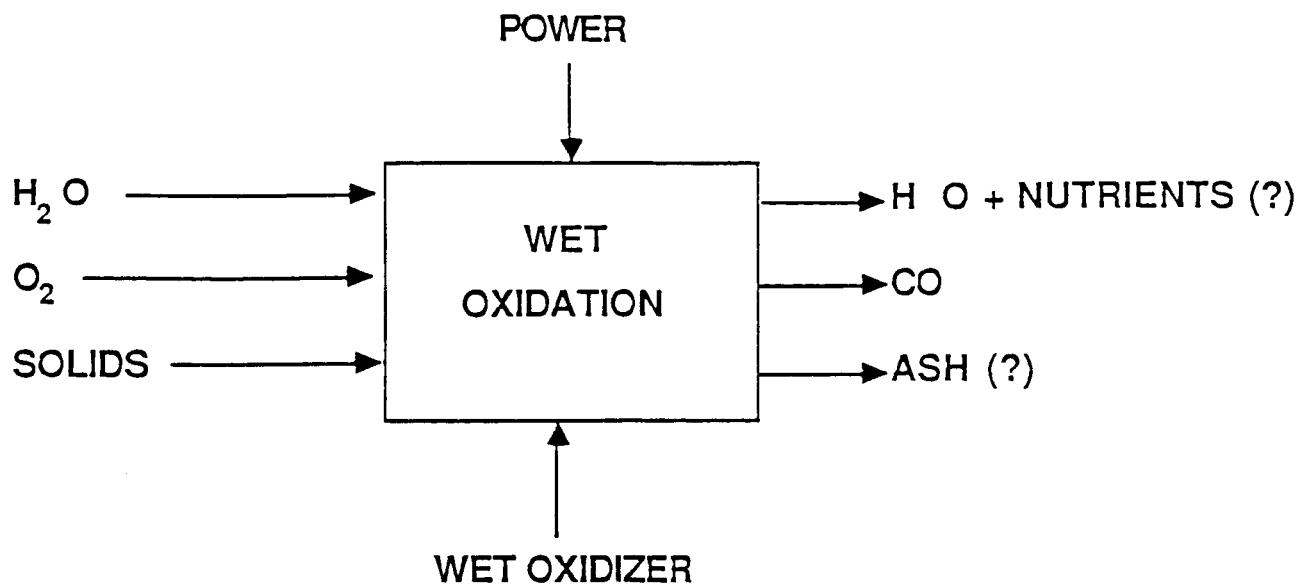
3- Wright - Methods of water processing for the Space Station.

7. Next meeting will be held on Monday, July 21 in room 202 of the ERC at 1:30 pm.









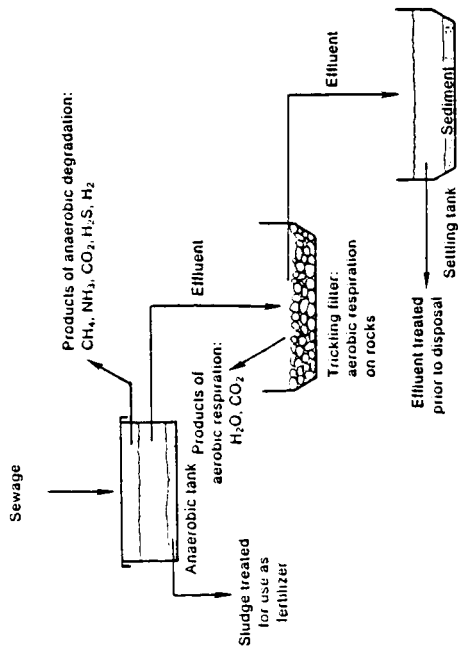


Fig. 1-23. Flow diagram illustrating biological sewage treatment involving anaerobic digestion within a percolating filter system. (See text for explanation.)

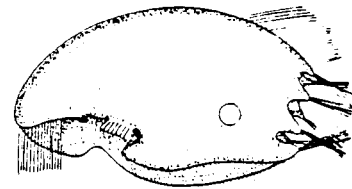


Fig. 1-24. *Epididymus*, a genus of ciliates commonly found in purifying sludge rich in hydrogen sulfide and deficient in oxygen (Scale = 10 μm .)

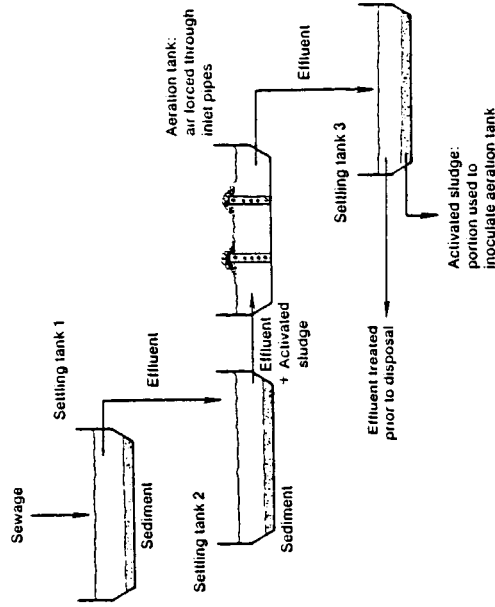


Fig. 1-25. Flow diagram illustrating biological sewage treatment involving aeration, flocculation, and the addition of "activated sludge" containing aerobic microorganisms such as *Bodo*, *Paramecium*, *Agardusia*, and *Vorticella*. (See text for explanation.)

In cases in which degradation of industrial wastes causes an accumulation of nitrates and phosphates, the settling tanks are illuminated to promote the growth of photosynthetic algae and protozoa, which, in turn, remove the inorganic materials from the water for their own synthesis. Water quality is improved, and the autotrophs are skimmed from the surface of the water, dried, and used as fertilizer.

In activated sludge systems (Fig. 1-25), the raw sewage is passed through large-mesh screens to break up the organic material before it is passed into a settling tank. An organic sludge accumulates on the bottom of the tank, most of which is permitted to dry and later to be treated for use as fertilizer. The effluent flows into aeration tanks, in which the fluid is stirred or aerated vigorously. "Activated sludge" is added here. Organic material begins to

clump or flocculate as a result of bacterial action. It has also been suggested that the mucoid secretion of sewage ciliates aids in the process of flocculation. Regardless, these flocs represent substrata for sessile ciliates. This turbid effluent is released into settling tanks from which the flocs are skimmed, and the detritus is permitted to settle to the bottom. The sediment in these tanks contains many aerobic microorganisms, including protozoa, which are the activated sludge used in the inoculation of the aeration tanks. Following a period of settling, the water having been treated with chlorine, is released into natural bodies of water.

Studies of the protozoan fauna of such systems indicate the prevalence of certain species. As would be expected, the majority are bacteria-feeding ciliates known to be tolerant of anaerobic conditions

RECON Meeting Summary
August 4, 1986

Attending: Duncan Hitchens, Gloria Johnson, James Magnuson, Bill Moses, Bob Murray, Oran Nicks, C.O. Patterson, Bud Peterson, Ed Rykiel, Ben Scharifker, John Schueller, Peter Sharpe, and Bruce Wright.

1. Oran Nicks - Introduction

Nicks reminded the group of the RTOP on closed life support systems and asked participation. Jerry Miller from Bioengineering attended a meeting at JSC on Biotechnology Programs. JSC is to receive an initial grant to develop tasks. The Project Review at JSC will be on August 13.

2. Bob Murray - Program Manager, Spacecraft Operations, Space Systems Division, General Electric

Murray presented information on the Integrated Waste and Water Management System which GE has offered to TAMU. When the system was fabricated about ten years ago, it ran for 200 days as an experiment, then it was put away and has not been used since. The cost to build a new system would cost more than double what it cost them to build this system. The best use of the system would be research and development to aid future space development -- lunar bases, etc. -- since the Space Station is already being developed.

3. Group Discussion

The group spent some time discussing the pros and cons of accepting the system. As setting up the system will be technical, not research, the group was concerned about:

1. Who will take responsibility for the system
2. Sources for the initial stage dollars
3. Support for a technician to maintain the system.

Some of the other ideas mentioned were:

1. Could take the individual pieces and use them for other things, if could not use the whole system.
2. This would be a chance to move into the experiment game next year, sooner than we could without it. Would not be starting from scratch to build a system.
3. It might take a year to set up, have it operational, and develop research to be done. Could start proposing ideas now, for next fiscal year.
4. If use of the hardware would enhance our proposal position, TEES might provide space and support for that reason.
5. Could write proposals with GE partnerships to NASA. Could propose for GE to provide a technician.
6. For SRC to go get it, need to see proposals to use it. Could set it up as a facility for use in research.

7. Having the system would provide a framework for research, will enhance our conceptual design, we can build on GE's experience.

There are risks involved in taking the system, but there are ideas for using it. Specific suggestions for research included:

1. Patterson - Could analyze output gases; examine the microbial population of the biodigester; stress the system with inputs like animal or poultry waste; analyze the ash products;
2. Sharpe - Could work with Phytoresources on projects, especially on capillary system plant growth.
3. Wright and Schueller - waste processing and nutrient cycling; hook up sealed chambers for plant growth. They were concerned about the attitude of TAES that growing plants in space is not important to Texas agriculture.
4. Peterson and Moses - update the system with the use of computers or strip chart recorders on the thermocouples, although the thermocoupling and data acquisition are technical, not research.
5. Hitchens and Scharifker - Improve the instrument, update, make more efficient; ideas of how to cope with the CO₂, exit gases; look at different methods from the Bausch reactor, update the electrolyzer.

Murray estimated that it would take 2 people about 2 months to set up and start the system, then a graduate student could maintain it.

The group decided:

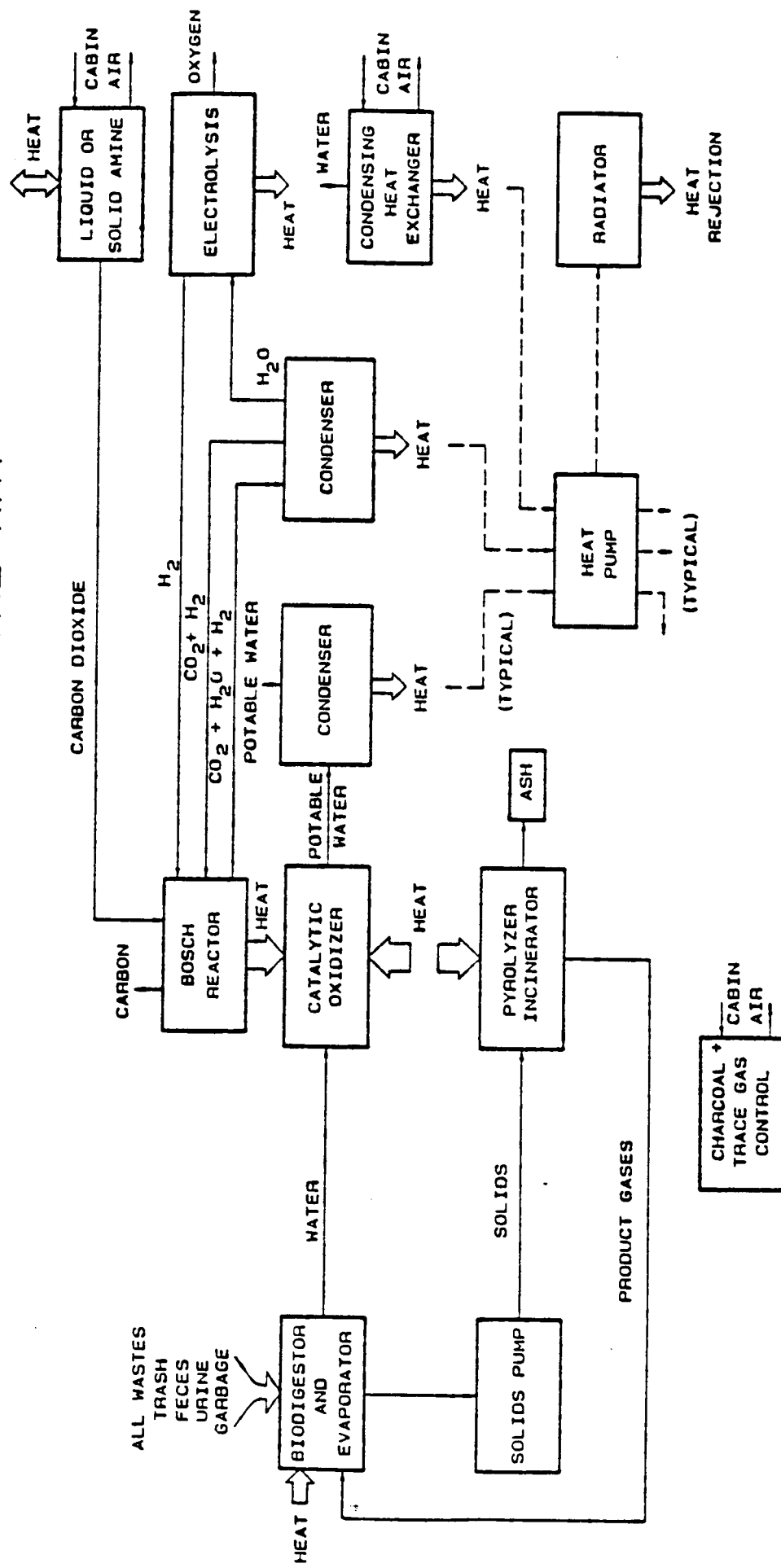
1. We want the system.
2. Whenever we find a place and GE is ready to bring it.
3. Nicks will talk to TEES, GE about support.
4. This month, need to write preliminary proposals for next year's efforts, factor in hardware.

Next week's meeting will be on Monday, August 11, in Room 202, ERC, at 1:30 p.m. Tim Hall's visit will be postponed until a majority of the group can be present. Instead, the presentation at JSC on August 13 will be discussed.

Action Items:

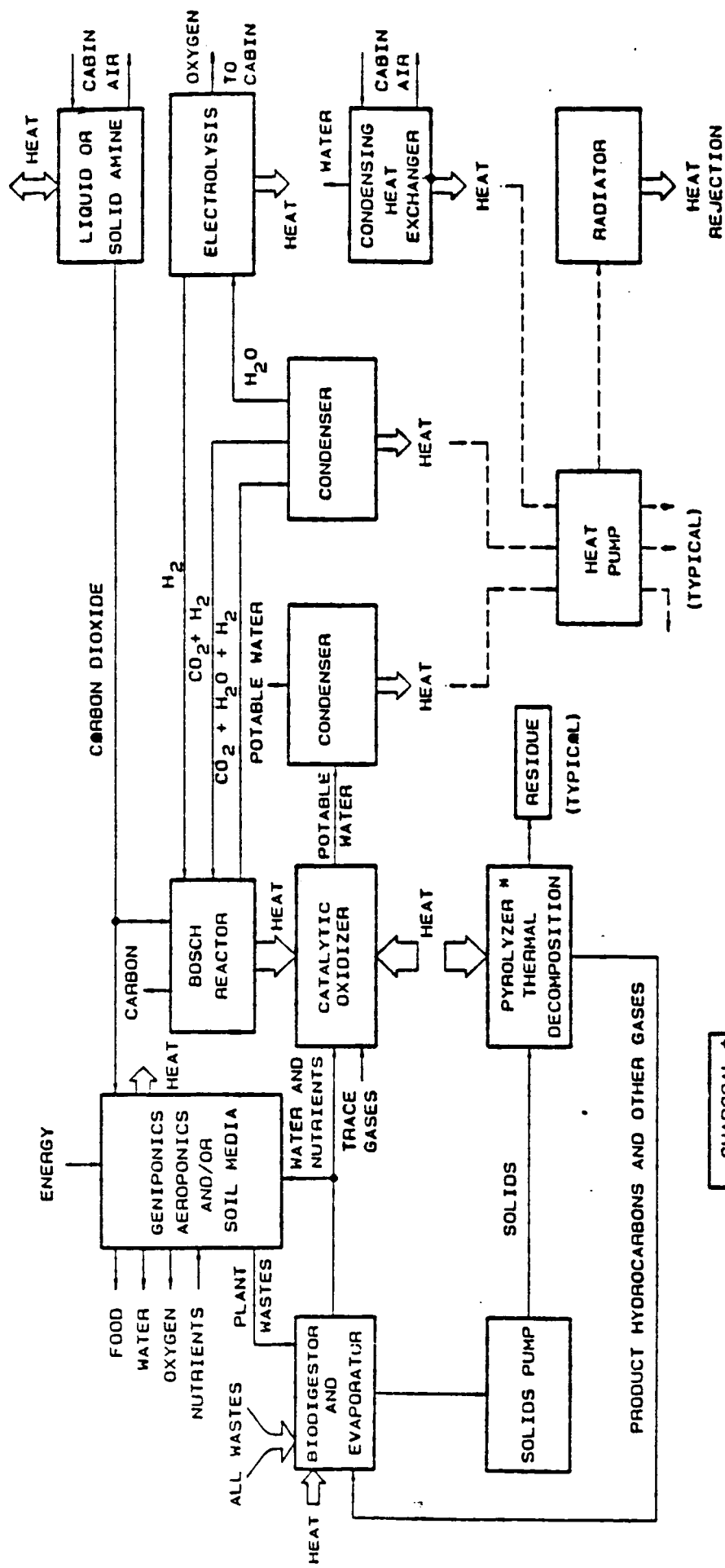
1. ALL - write preliminary proposals for research next year.
2. Nicks - talk with TEES, GE about support and space for the system.

CANDIDATE FIRST STEP TO CELSS
(MOSTLY PHYSICOCHEMICAL PROCESSES)
PRESENT STATE-OF-THE-ART



**+ CAN INCLUDE
LOW TEMP. CATALYSTS**

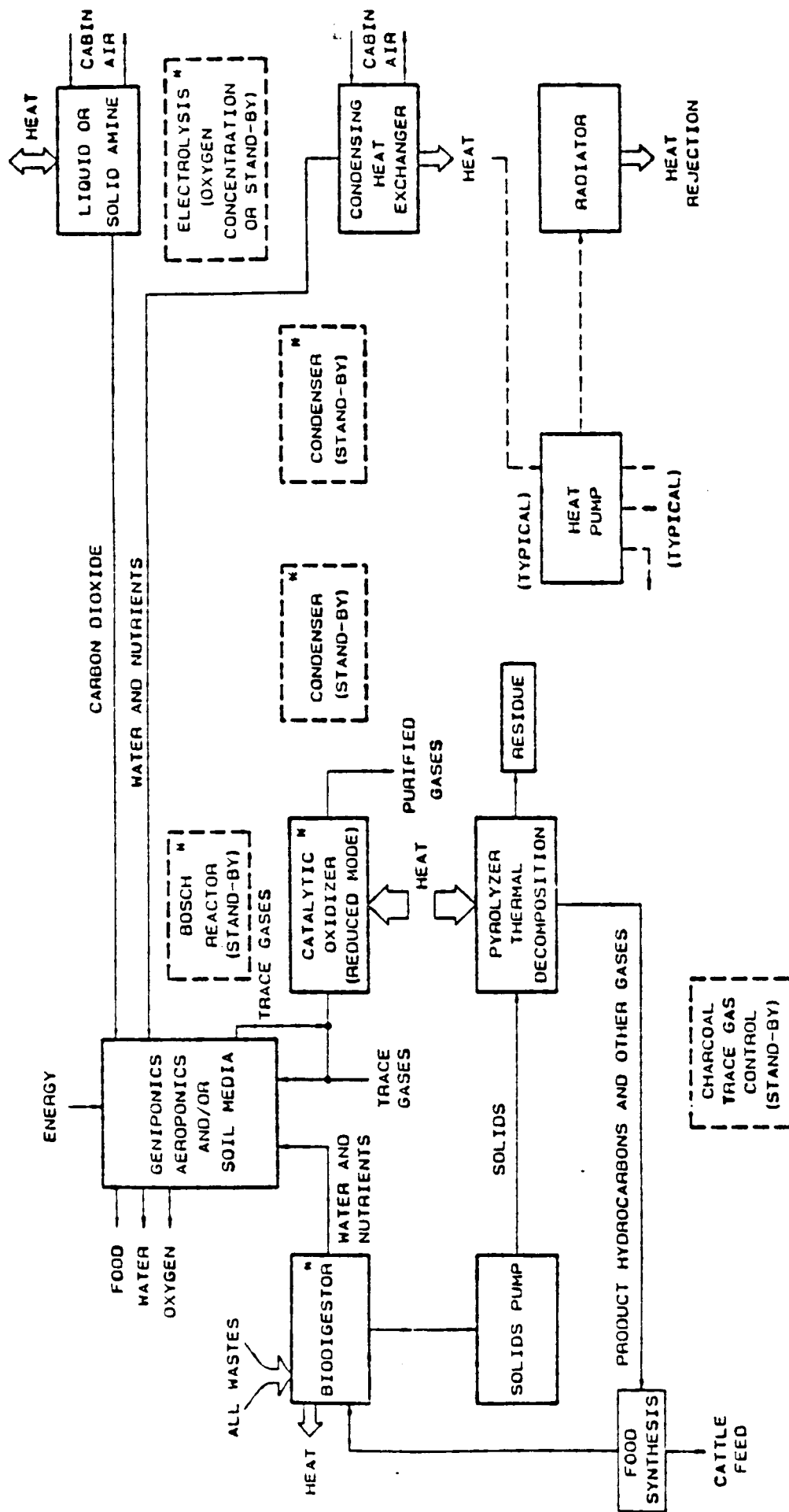
CANDIDATE SECOND STEP TO CELSS (MORE RELIANCE ON BIOLOGICAL PROCESSES)



* CHANGE IN OPERATION
OR FUNCTION FROM
FIRST STEP

+ CAN INCLUDE
LOW TEMP. CATALYSTS

CANDIDATE THIRD STEP TO CELSS (MOSTLY BIOLOGICAL PROCESSES)



* CHANGE IN OPERATION
OR FUNCTION FROM
FIRST STEP

RECON Meeting Summary
September 15, 1986

Attending: Duncan Hitchens, Gloria Johnson, Oran Nicks, C.O. Patterson, Bud Peterson, and Harold Slater

1. Harold Slater - O₂ requirements

Slater reported on his literature search for information on the leaf area required to provide oxygen for humans. There was a project involving wheat production in controlled environments in space. It did not look at low pressure effects. Effects of higher concentrations of CO₂ at 2,000 ppm.

Slater's summary is attached. He estimates approximately 5 square meters of leaf area will be required to provide oxygen for each man.

There was discussion about his estimate. He will pursue additional literature on the subject.

2. C.O. Patterson - proposal for algal culture (attached)

Patterson's proposal starts with the RITE System, and modifies it to do other things. There was discussion about the proposal and its assumption that the RITE System is ready for use. Since we have two or three projections for experiments requiring engineering help, we need engineering input to develop the proposals, tie them all together. Patterson and Peterson will set up a meeting to discuss ways of integrating the engineering help into the proposals, and discuss budget requirements to do so.

Their meeting will be Friday, September 19, 3:30 p.m., Room 204C, Evans Library. All members of the group are invited to attend.

Next week's RECON group meeting will be on Monday, September 22, in Room 316, Teague Building, at 3:30 p.m. **Please contact Gloria ahead of time if you cannot attend the weekly meeting.**

Action Items:

1. Slater - continue research on leaf area requirements
2. Patterson and Peterson - set up meeting, discuss integrating engineering plans into the proposals

1. A Standard man is 70 Kg.
2. The standard man requires a minimum of 2000 Kcal to exist; but if he sleeps 8 hrs, sits 5 hrs, exercises lightly for 7 hrs, actively for 3 hrs, severely for 1 hrs, then he requires 3530 Kcal/Day.
 A. A labor on earth can utilize 6000 Kcal/Day
 B. Thus the Standard Man is space utilizes 3600 Kcal/Day

3. The Standard Man has a Respiratory Exchange Ratio ($R = \frac{\text{CO}_2 \text{ output}}{\text{O}_2 \text{ intake}}$) of 0.825

4. The Standard Man (American) gets 15% of his energy from protein, 40% from fat, and 45% from carbohydrates.

5. For the Average man's diet 1 liter of O_2 is utilized to produce 4.825 Kcal.

6. Therefore, the Average man's O_2 requirement is:

$$\frac{3600 \frac{\text{Kcal}}{\text{Day}}}{4.825 \frac{\text{Kcal}}{\text{L O}_2}} = 746 \text{ liter O}_2/\text{Day} \text{ or } 33.3 \text{ Moles O}_2/\text{Day}.$$

7. $\text{CO}_2 \text{ Released/Day} = 33.3 \frac{\text{moles O}_2}{\text{Day}} \times 0.825 = 27.5 \text{ Moles CO}_2/\text{Day}$

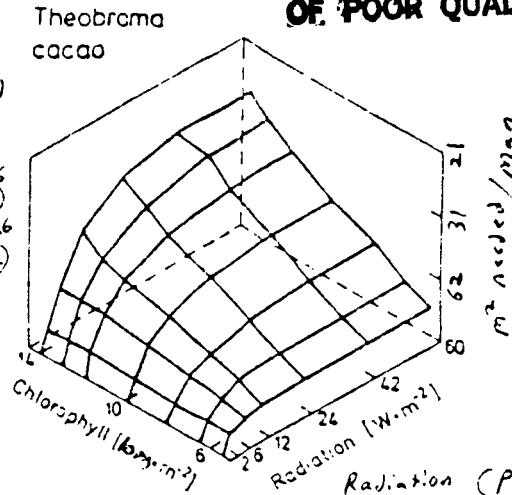
8. The above analysis assumes that O_2 consumption is correlated with heat evolved from the body, and that the energy consuming processes & requirements are likewise expressed as energy evolved from the body as heat.

9. ECLSS estimation is 36.15 moles O_2 /man-Day (Doc. # CSD-SS-059), and 31.44 moles CO_2 /man-Day.

10. C. O. Patterson's estimates 28.35 moles O_2 /man-Day

ORIGINAL PAGE IS
OF POOR QUALITY

| TYPE of Plant | O ₂ ↑ | needed m ² |
|----------------|------------------|-----------------------|
| C ₄ | 30-80 (108) | 20-7.6 (5.7) |
| C ₃ | 20-45 (60) | 4-13.6 (10.2) |

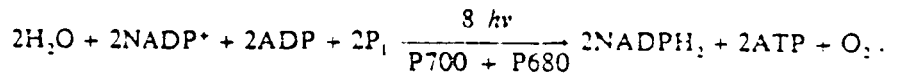


Relationship between potential photosynthesis under illumination of different intensities and the chlorophyll content of maturing cocoa leaves. Chlorophylls a and b are present in the same ratio over the entire range of variation. The measurements were done in CO₂-saturated conditions (2400 μl CO₂ per liter air) to ensure that the rate of photosynthesis was not limited by the secondary processes (Baker and Hardwick, 1976)

A. 30 m² of wheat need for food production and 16.4 m² for O₂ evolution.

* all calculation assume that 1 O₂ is released per CO₂ taken-up. This is very conservative.

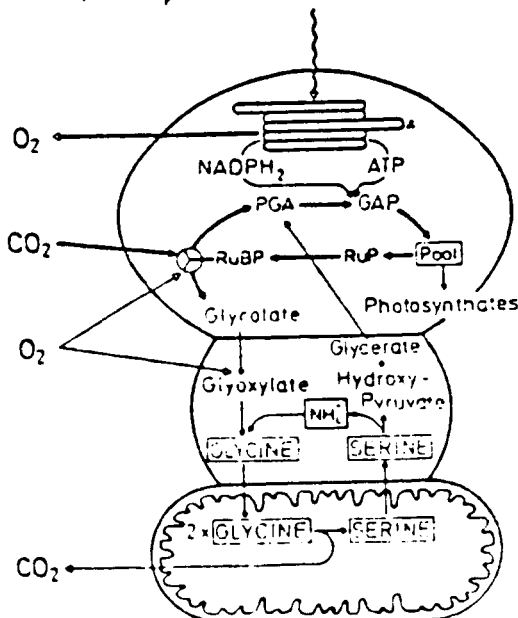
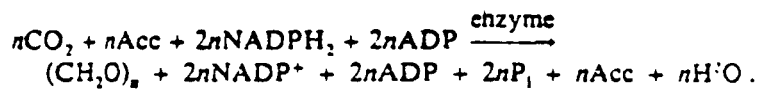
II. Light reaction of P₃ →



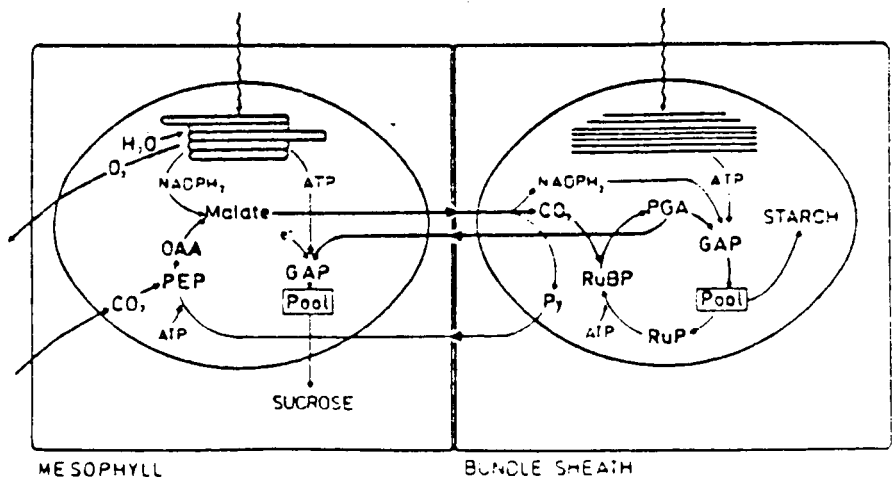
$$\Phi = \frac{\text{Photochemical activity (mol O}_2\text{)}}{\text{Absorbed photons (einsteins)}}$$

The quantum yield of photosynthesis depends primarily on the *spectral composition of the light* and the *photon flux*. As long as radiation is the sole rate-limiting factor, the intensity of photosynthesis increases in proportion to the photon flux. A steep slope of the light-dependence curve (see Chap. 3.2.3.1) thus reflects good utilization of quanta. Under favorable conditions plants can achieve quantum yields of 0.05–0.1 mol O₂ per einstein, which corresponds to 33% utilization. However, on the average the quantum yield, and thus the effectiveness with which radiation is utilized is, lower: this is because, in strong light especially, the secondary processes of photosynthesis become rate limiting.

III. Chemical reaction of Photosynthesis →



C₃ Photosynthesis



C₄ Photosynthesis

RECON Meeting Summary
September 22, 1986

Attending: Gloria Johnson, Frank Little, Bill Moses, Oran Nicks, C.O. Patterson, Bud Peterson, Ed Rykiel, Harold Slater, and Bruce Wright.

1. Nicks - Status reports

Nicks discussed the project with Al Chambers at NASA Ames. Ames will continue to be involved in cells research. They are interested in what we are doing, Chambers thinks it is a good idea, would be supportive to have the science done. He is not competitive with JSC and KSC.

The Air Force was involved in CLSS at San Antonio in the early 70's, Rich Miller at Brooks and Herb Ward. Patterson talked with Ward, who now is a professor of Civil Engineering at Rice. They are both still interested, and are congenial, but are now in other work. They tried to fly an algae experiment, but the culture vessel failed on takeoff.

Bob Murray of GE submitted suggestions for in-flight experiments. His letter is attached. He outlined the following possibilities:

1. Non-venting EC/LSS Development
2. Integrated Biowaste and Trash Management
3. Thermal Integration of EC/LSS Processes
4. Commonized EC/LSS Process and Equipment Designs

2. Proposal discussion

The proposals for JSC FY87 were discussed at length. Three proposals are being considered for inclusion in the package:

1. Concept Modeling
2. Algal growth experiments
3. Low pressure chambers for higher plant growth
4. Solid waste experiment

Attached are a tentative RECON Plan and a sketch which the group developed showing how the RITE System can be used to tie together the experiments being proposed. Time is short for rewriting and submitting the proposals. They are due at JSC on October 1, but time must be allowed for the Research Foundation to develop budgets and get signatures from various departments on campus, before mailing.

Next week's meeting will be on Monday, September 29, in Room 316, Teague Building, at 3:30 p.m.

Action Items:

All - develop proposals for submission to JSC.

RECON PLAN

CONCEPT Phase 4

Initiate systems test with
closed ECLSS

Develop concept models
for Lunar base

SYSTEM Phase 3

Integrate Systems
Experiments with RITE

Obtain Engineering Design
Parametric Data

Upgrade concept models

NASA

INDUSTRY

AIR FORCE

Support
for use of
facility

EXPERIMENT Phase 2

Develop AI Model

Initiate Experiments

1. algae
2. higher plants
3. waste recycling

Define Research Facility
including

1. RITE
2. Growth chambers
3. Algal equipment

STUDY Phase 1

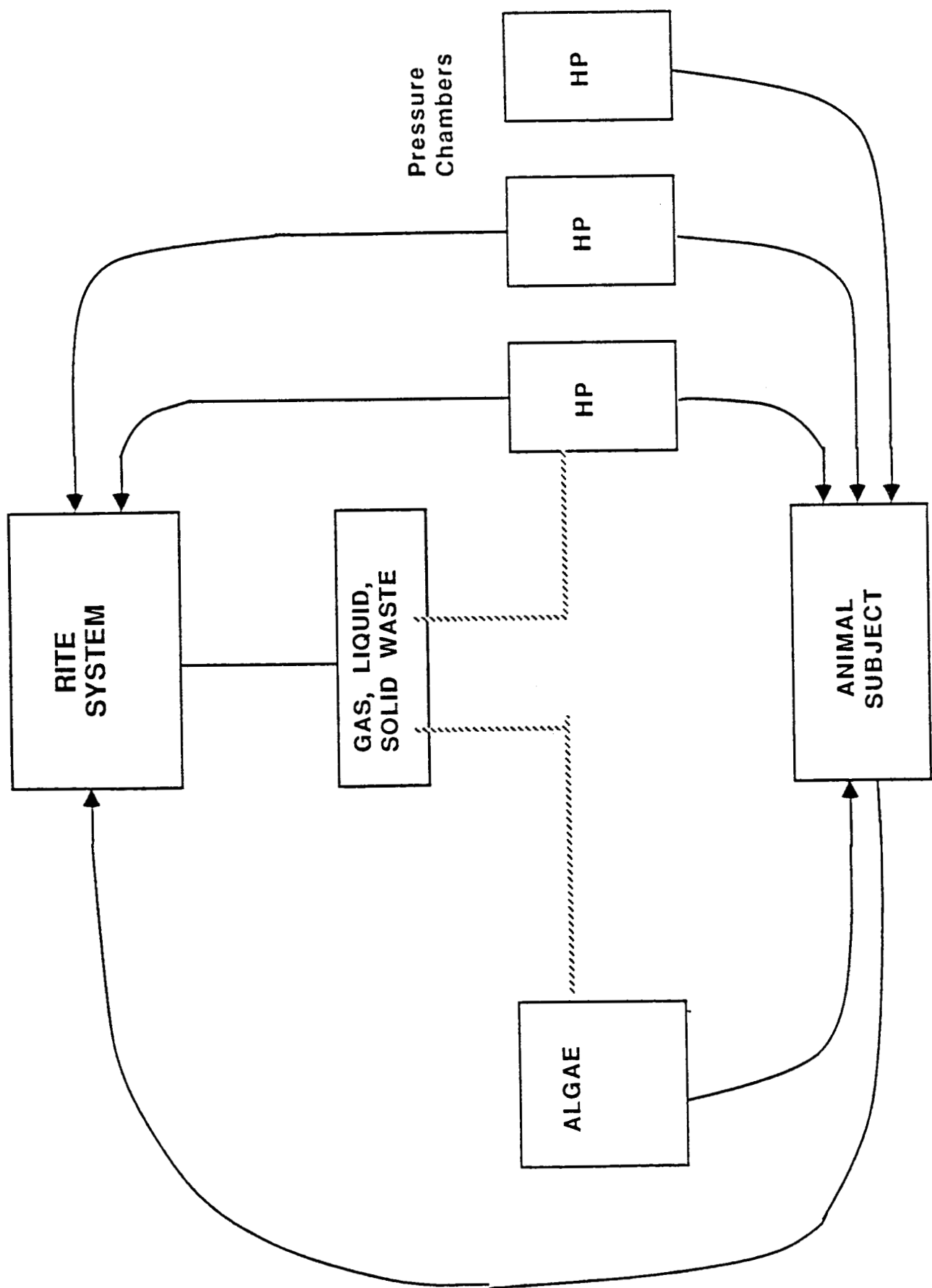
Team building

Outline systems concepts

Identify critical techniques

Data base collection

Function modeling



RECON Meeting Summary September 29, 1986

Attending: Duncan Hitchens, Gloria Johnson, Ramesh Kainthla, Bill Moses, Oran Nicks, C.O. Patterson, Bud Peterson, Ed Rykiel, Harold Slater, and Bruce Wright.

The group looked at the Tasks in the project proposal, and discussed project status at length. They developed the following table illustrating known life support regenerative concepts.

Proven Space Regen Concepts - Life support

- | | |
|--|-------------------|
| 1. Water processing to potable, reclamation , ~98% | <u>Processing</u> |
| 2. Atmosphere - dehumidify, scrub CO ₂ | Atmosphere |
| | Water |
| | Food |
| 3. Food - no regeneration | Waste |
| 4. Solid Waste - no regeneration | |

Possible Under Laboratory Conditions

1. Water reclamation, or regeneration
2. Atmosphere - biological processing
3. Food - biological processing with gravity
4. Solid Waste - biochemical processing with gravity

Assumptions Needed to Plan for Closed Systems

1. External energy source
2. All products launched needed to close cycle, not necessarily in form to be used.
3. Some losses and some resupply will be required.

Next week's meeting will be on Monday, October 6, in Room 316, Teague Building, at 3:30 p.m.

Action Items: All - Continue working on the project, as started at this meeting.

RECON Meeting Summary

October 6, 1986

Attending: Frank Little, C. O. Patterson, Harold Slater, Bill Moses, Bud Peterson, Duncan Hitchens, Oran Nicks and Marta McMurray.

1. Nicks - The proposals were sent to JSC and two other NASA centers. A copy of the proposals was passed around to those present for review. A copy will be included with the minutes of this meeting.

Nicks read the specifications for the closed life support systems in a publication entitled "Engineering and Configurations of Space Stations and Platforms" (NASA). Which describes the need for gas exchange parameters.

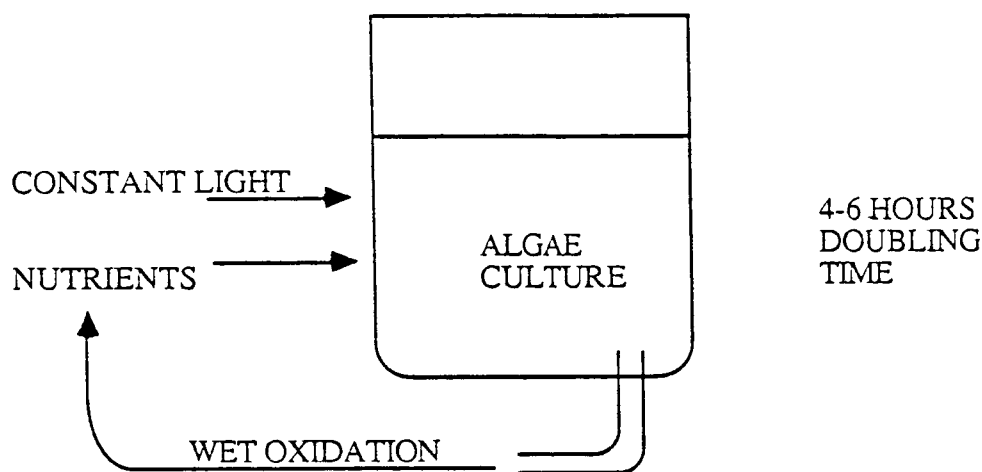
2. Patterson distributed copies of articles on Atmospheric Closure; one article in 1964 in which they accomplished 98% closure, another article from March, 1986 in which the authors tried to repeat the previous experiment including the effects of different forms of Nitrogen on algal growth. And a bibliography done in the 1970's of the requirements for atmospheric regeneration using algal systems, including volume requirements, modes of operation, illumination, area illuminated, watt requirements, etc. All of these were done under idealized conditions and none included humans. This demonstrates that a fair amount of information is available, but most of the data is 20 years old, none less than ten years. Most experiments included all containers made of glass and used small mammals. Would contaminants have an effect on the system and its components?

Cultivation of algae started 75 years ago with *Chlorella* which is the most common. Later, blue-green algae studies and cultures were developed. Patterson would use two criteria for studying certain species of algae. 1) suitability for human consumption; 2) ease of repetitive growth.

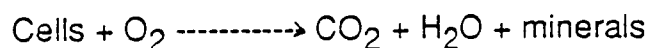
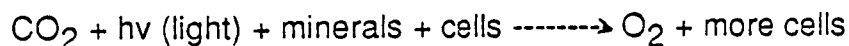
Nicks: We need to know how much this is to gain by closed systems. How are we going to close both systems of gas and food?

Algae are more efficient for gas exchange alone because they make O_2 only; they are freely suspended in H_2O ; do not orient toward gravitational fields and therefore can grow in zero G. They have not been considered good until now because their value as human food has only recently been recognized. It would be best to leave the food production to the higher plants.

An explanation of what it takes to grow algae:



They reach a standard population in 36 to 48 hours. Then the nutrients or light are regulated to adjust the regeneration time to maintain steady output of oxygen and steady increase of cell mass. The algae can be reused for their own nutrients by doing a complete wet oxidation.



In animals the Respiratory Quotient or RQ equals:

$$RQ = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$$

RECON Summary, October 6, 1986

If the animal were all carbohydrate, then the $RQ = 1$, but animals are part protein, so you have $NH_3 + O_2 \rightarrow NO_3$ and the real RQ ends up equaling more like 0.8-0.9. The Assimilatory Quotient (reverse of RQ) equals:

$$AQ = \frac{CO_2 \text{ consumed}}{O_2 \text{ produced}}$$

if plants were carbohydrate alone, it would be equal to 1, but they are not, so:

$NO_3 + H_2 = NH_3$, consequently, the AQ is 0.8-0.9.

If $RQ = AQ$, there is no difficulty in keeping the system in balance. Because in reality they are not equal, there is some imbalance.

Now what the group has to do is make the experiment an engineering system design.

NEXT MEETING - MONDAY, OCTOBER 13, IN ROOM 316, TEAGUE BUILDING, AT 3:30 PM.

ACTION ITEMS:

Patterson - write up the experiment needs for one human being and give these numbers to the Peterson and the other engineers and let them make the engineering design.

mlm

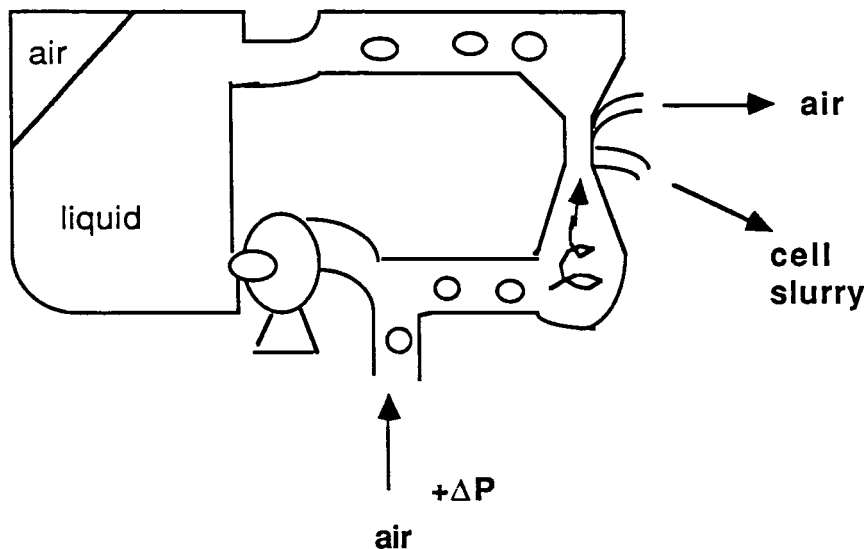
Enclosures: Proposals to JSC
Copy of ECLSS Description by NASA

RECON Meeting Summary October 13, 1986

Attending: Duncan Hitchens, Gloria Johnson, Bill Moses, Oran Nicks, C.O. Patterson, Bud Peterson, Harold Slater, and Bruce Wright.

1. Wright - cyclone separator

Bruce drew the following sketch of a cyclone separator, for possible use in algae growth.



2. KEE Update

Rykiel was not present, but he sent word that he went to MCC last week and brought back four more Xerox workstations. Now, he has one for his use, and it works. He is attending a shortcourse on function modeling which Rick Mayer is teaching. When Ed is ready, he wants to invite Jane Malin to come up and demonstrate the work that she did at JSC using KEE software.

3. Patterson - Summary of the design specifications for algal bio-reactors

C.O. presented his summary and it was discussed (copy attached). Peterson and Moses will take the specifications and do the conceptual engineering as a starting point for developing a concept that can be used on the moon. The bio-reactors in his summary have been used for years, and the engineers will try to come up with a better engineering design.

4. RITE System Location

We still need laboratory space for the RITE System, before we can make arrangements to accept it. There are still two possibilities: (1) with Agricultural Engineering in Scoates, possibly using some cold rooms which are there; (2) the ERC, if space can be located there. Nicks will continue to pursue the space problem with Ken Hall at TEES and Bob Merrifield at TAES.

5. Mid-Term Project Report

The Mid-Term Project Report will be due on November 15. We will need to summarize what we have done, to inform the sponsor and other potential sponsors. As there is a dearth of information on integrated systems, we are doing a first look, and are in a position to take a lead role. Nicks and Johnson will outline the report, and give out a draft for the group to redo, with some of the group members contributing information in their areas.

Next week's meeting will be on Monday, October 20, in Room 316, Teague Building, at 3:30 p.m. Please contact Gloria if you are not able to attend.

Action Items for next week:

1. Ed Rykiel - Tell us where we go from here on function modeling.
2. All - start on "straw man" model by hand, in preparation for doing the function modeling.
3. Peterson and Moses - start on engineering design for algae growth